Environment CANADA Environnement
10209261 VOL ISS 86 860700
EXC # 001
TD 171.5.C3 R46
REPORT EE

OOFF

FOLLOW-UP STUDY OF A SULPHURIC ACID SPILL

NEAR SPRINGHILL, NOVA SCOTIA

EE-86

FOLLOW-UP STUDY OF A SULPHURIC ACID SPILL NEAR SPRINGHILL, NOVA SCOTIA

by

R. Lamoureux, J. Duff, S. Colville
MacLaren Plansearch Limited
Halifax, Nova Scotia

and

P. Lane, M. Crowell, J. Wright
P. Lane and Associates Limited
Halifax, Nova Scotia

This report has not undergone detailed technical review by Conservation and Protection and the content does not necessarily reflect the views and policies of Environment Canada. Mention of trade names or commercial products does not constitute endorsement for use.

This unedited version is undergoing a limited distribution to transfer the information to people working in related studies. This distribution is not intended to signify publication and, if the report is referenced, the author should cite it as an unpublished report of the Branch indicated below.

Any comments concerning its content should be directed to:

Environment Canada
Environmental Protection Directorate
River Road Environmental Technology Centre
Ottawa K1A 0E7

EE-86

July 1986

ABSTRACT

A field study of the effects of a spill of concentrated sulphuric acid from a railway tank car was undertaken in the fall of 1985, seven complete growing seasons after the accident. The study was undertaken in an area of well drained, naturally acidic soils near Springhill, Nova Scotia. The work included the preparation of a vegetation map; analysis of the composition of shrub and ground vegetation communities; analysis of the growth rates of shrubs; mapping of soils and soil pH; and detailed examination of key soil chemistry parameters.

Although the acid spill caused substantial mortality to the shrub vegetation of the site, shrub growth rates returned to pre-spill levels within three to four growing seasons. Areas disturbed by acid were colonized by shrub species such as Gray Birch (Betula populifolia), Downy Alder (Alnus crispa), Beaked Willow (Salix Bebbiana) and Pin Cherry (Prunus pensylvanica). No distinctive ground vegetation communities were associated exclusively with the spill area.

Depressed pH levels were still observable after seven growing seasons at some sampling locations. However, the pattern of data on soil chemistry parameters was complex and not always consistent with expectations arising from the observed pH levels. This may be due partly to the passage of time, which may have masked some of the cause and effect relationships, and partly to the heterogeneity of the soils of the site.

Areas that were disturbed by grading and the placement of fill at the time of the spill have shown very poor recovery of vegetation. This suggests that the terrain disruption incidental to the spill has had much more lasting effects than the spill itself.

As a result of the study it has been concluded that acidization of the soil is a reversible phenomena that should not be treated as an environmental emergency unless other resources, such as aquatic life, are threatened. Terrain disturbance should be kept to a minimum immediately after a spill. Conventional practices to counter low soil pH, such as the application of agricultural lime should be initiated as part of a planned long-term program of land restoration. The land restoration program should be undertaken in consultation with a local soils specialist, and should be based on results of laboratory analysis of the impacted soils.

RÉSUMÉ

Les effets d'un déversement d'acide sulfurique concentré par un wagon-citerne ont été étudiés à l'automne de 1985, sept saisons de croissance complètes après l'accident. L'étude a été effectuée dans une région située près de Springhill, en Nouvelle-Écosse, où les sols naturellement acides sont bien drainés. Les travaux comprenaient l'établissement d'une carte de la végétation; l'analyse de la composition des groupes d'arbustes et de la couverture végétale au niveau du sol; l'analyse du taux de croissance des arbustes; la cartographie des sols et du pH des sols; et l'examen détaillé des principaux paramètres de la chimie des sols.

Même si le déversement de l'acide a provoqué une mortalité considérable parmi la végétation arbustive du site, les taux de croissance des arbustes sont revenus à la normale, trois ou quatre saisons de croissance après le déversement. Les aires perturbées par l'acide étaient colonisées par des espèces d'arbustes comme le bouleau gris (Betula populifolia), l'aulne crispé (Alnus crispa), le saule de Bebb (Salix Bebbiana) et le cerisier de Pensylvanie (Prunus pensylvanica). Aucun groupe de plantes poussant au niveau du sol n'a été associé exclusivement à l'aire de déversement.

Des concentrations réduites de pH étaient toujours observables, après sept saisons de croissance, à certains emplacements d'échantillonnage. Toutefois, le diagramme des données sur les paramètres de la chimie du sol était complexe et ne coïncidait pas toujours avec les prévisions faites d'après les concentrations observées du pH. Cela peut être attribuable en partie à l'écoulement du temps qui peut avoir masqué certaines relations de cause à effet, et en partie à l'hétérogénéité des sols du site.

La végétation a très mal récupéré dans les aires perturbées par le terrassement et le remblayage au moment du déversement. Cela indique que la perturbation du terrain après le déversement a eu des effets beaucoup plus durables que le déversement lui-même.

Entre autres résultats, l'étude a permis de conclure que l'acidification du sol est un phénomène réversible qui ne doit pas être traité comme une urgence environnementale à moins que d'autres ressources, comme la vie aquatique, ne soient menacées. Immédiatement après un déversement, un terrain doit être perturbé le moins possible. Pour contrer le faible pH du sol, il faut faire appel à des méthodes traditionnelles, comme l'épandange de chaux utilisée en agriculture comme étape initiale d'un programme à long terme de rétablissement des terres. Le programme de remise en état des terres doit être réalisé de concert avec un spécialiste local des sols et doit être fondé sur les résultats d'analyses en laboratoire des sols perturbés.

TABLE OF CONTENTS

		Page
	Abstract	
1.	INTRODUCTION	1
2.	RECONSTRUCTION OF SPILL EVENT	2
3.	THE STUDY AREA	7
4.	THE STUDY PROGRAM	10
	4.1 VEGETATION STUDIES	10
	4.1.1 Shrubs	12
	4.1.2 Ground Vegetation	12
	4.1.3 Shrub Growth Ring Studies	13
	4.2 SOILS STUDIES	14
	4.2.1 Soils Mapping	14
	4.2.2 pH Measurements	14
	4.2.3 Soil Chemistry	16
	4.3 MULTIVARIATE ANALYSIS	16
	4.4 LITERATURE SEARCH	16
5.	RESULTS	18
	5.1 VEGETATION OF THE SITE - AN OVERVIEW	18
	5.2 EVIDENCE OF PERTURBATION OF VEGETATION	23
	5.2.1 Comparison of Shrub Ages	23
	5.2.2 Comparison of Basal Areas of Shrubs	25
	5.2.3 Shrub Growth Trends and Rates	27
	5.3 IMPACTS OF SPILL ON PLANT SPECIES COMPOSITION	37
	5.3.1 Distribution of Plant Communities	37
	5.3.2 Distribution of Shrub Species	38
	5.3.3 Ground Vegetation	43
	5.4 MULTIVARIATE ANALYSIS OF VEGETATION DATA	48
	5.5 SOILS OF THE STUDY AREA	51

TABLE OF CONTENTS

(Cont'd)

		Page
5.6	SOIL CHEMISTRY	54
5.6.1	Soil pH	54
5.6.2	Exchangeable Aluminum	58
5.6.3	Titratable Acidity	60
5.6.4	Exchangeable Bases	62
5.6.5	Sulphate	68
5.6.6	Electrical Conductivity	70
5.6.7	Cation Exchange Capacity and Percent Base Saturation	70
5.7	CLUSTER ANALYSIS OF SOILS VARIABLES	73
5.8	INTEGRATED CLUSTER ANALYSIS OF VEGETATION AND SOILS DATA	73
5.9	SUMMARY	76
6.	DISCUSSION	80
6.1	LESSONS LEARNED FROM SPRINGHILL SPILL	80
6.2	LESSONS LEARNED FROM OTHER SPILLS	81
6.3	RECOMMENDATIONS OF OTHER RESEARCHERS	84
6.4	STUDY TEAM RECOMMENDATIONS	85
6.4.1	Security Considerations	86
6.4.2	Spill Trajectories	86
6.4.3	Available Resources and Immediate Response Plan	86
6.4.4	pH Monitoring	87
6.4.5	Expert Advice	87
6.4.6	Implementation of Immediate Response Plan	87
6.4.7	Documentation of Spill Location	89
6.4.8	Post-Spill Monitoring	90
6.4.9	Long-Term Restoration Plan	90
6.5	FUTURE RESEARCH	92
7.	REFERENCES	94
APPENDIX A	MULTIVARIATE ANALYSIS	97

LIST OF TABLES

		Page
Table 1	Description of Mapped Plant Communities	20
Table 2	Species List for Shrubs	21
Table 3	Species List for Ground Layer of Vegetation	22
Table 4	Mean Growth Rates of Hawthorn (Crataegus macrosperma) in Undisturbed and Acidified Quadrats for the Last Five Years	33
Table 5	Mean Growth Rates of Hawthorn (Crataegus macrosperma) in Undisturbed and Acidified Quadrats during the First Five Years of Shrub Growth	35
Table 6	Mean Growth Rates of Four to Seven Year Old Hawthorn (Crataegus macrosperma) in Undisturbed and Acidified Quadrats during the Last Five Years	36
Table 7	Distribution of Species of the Ground Layer of Vegetation in the Four Environmental Zones of the Detailed Study Area	46
Table 8	Soil Chemistry Data for the Detailed Study Area	55
Table 9	Soil pH Measurements from the Overall Study Area	56

LIST OF FIGURES

		Page
Figure 1	Location of Acid Spill	3
Figure 2	Reconstruction of Acid Spill	4
Figure 3	Study Area	8
Figure 4	Sampling Quadrats in Detailed Study Area	11
Figure 5	Soil Observation and Sampling Pits	15
Figure 6	Vegetation Map	19
Figure 7	Mean Ages of Shrubs in the 5m x 5m Quadrats	24
Figure 8	The Four Environmental Zones in the Detailed Study Area	26
Figure 9	Basal Area of Shrubs (per Hectare) in 5m x 5m Quadrats	28
Figure 10	Growth Trends of Hawthorn	29
Figure 11	Relative Frequency of Four Shrub Growth Trends	31
Figure 12	Distribution of Basal Area of Gray Birch (Betula populifolia)	39
Figure 13	Distribution of Basal Area of Downy Alder (Alnus crispa)	40
Figure 14	Distribution of Basal Area of Beaked Willow (Salix bebbiana)	41

LIST OF FIGURES (Cont'd)

		Page
Figure 15	Distribution Basal Area of Pin Cherry (Prunus pensylvanica)	42
Figure 16	Distribution of Basal Area of Hawthorn (Crataegus macrosperma)	44
Figure 17	Ratio of Basal Area of Hawthorn (Crataegus macrosperma) to Basal Area of All Shrubs	45
Figure 18	Results of Cluster Analysis for Shrubs	49
Figure 19	Results of Cluster Analysis for Ground Vegetation	50
Figure 20	Soils Map (Total Study Area)	52
Figure 21	Soils Map of Detailed Study Area	53
Figure 22	pH in $CaCl_2$ (Total Study Area)	57
Figure 23	pH in $CaCl_2$ (Detailed Study Area)	59
Figure 24	Exchangeable Aluminum (Al^{3+})	61
Figure 25	Exchangeable Calcium (Ca^{2+})	63
Figure 26	Exchangeable Magnesium (Mg^{2+})	64
Figure 27	Exchangeable Potassium (K^{+})	65
Figure 28	Exchangeable Sodium (Na^{+})	66

LIST OF FIGURES (Cont'd)

		Page
Figure 29	Sulphate (SO_4^{2-})	69
Figure 30	Electrical Conductivity	71
Figure 31	Percent Base Saturation	72
Figure 32	Results of Cluster Analysis of Soils Variables	74
Figure 33	Results of Integrated Cluster Analysis of Vegetation and Soils Data	75

1. INTRODUCTION

On December 13, 1978, a railway tank car of concentrated (93%) sulphuric acid was spilled as a result of a train derailment about 10 km northwest of the town of Springhill, Nova Scotia.

The spill caused visible damage to vegetation over a limited area. In the fall of 1985, seven growing seasons after the spill, Environment Canada contracted MacLaren Plansearch Limited, in association with P. Lane & Associates Limited, to undertake a study to document the effects of the spill and to make recommendations on appropriate response measures for future spills of sulphuric acid. This report describes the results of that study.

2. RECONSTRUCTION OF SPILL EVENT

At 13:55 hours on December 13, 1978, an eastbound freight train travelling at approximately 40 mph (64 km/h) derailed between mile 63.05 and 62.80 of the Springhill Subdivision of the CN mainline (see Figure 1). A total of 51 cars were derailed. One railway tank car, containing concentrated (93%) sulphuric acid, was ruptured and almost its entire contents were spilled. The tank car came to rest lying transversely across the railway right-of-way, with acid leaking rapidly from a large hole in one end (See Figure 2).

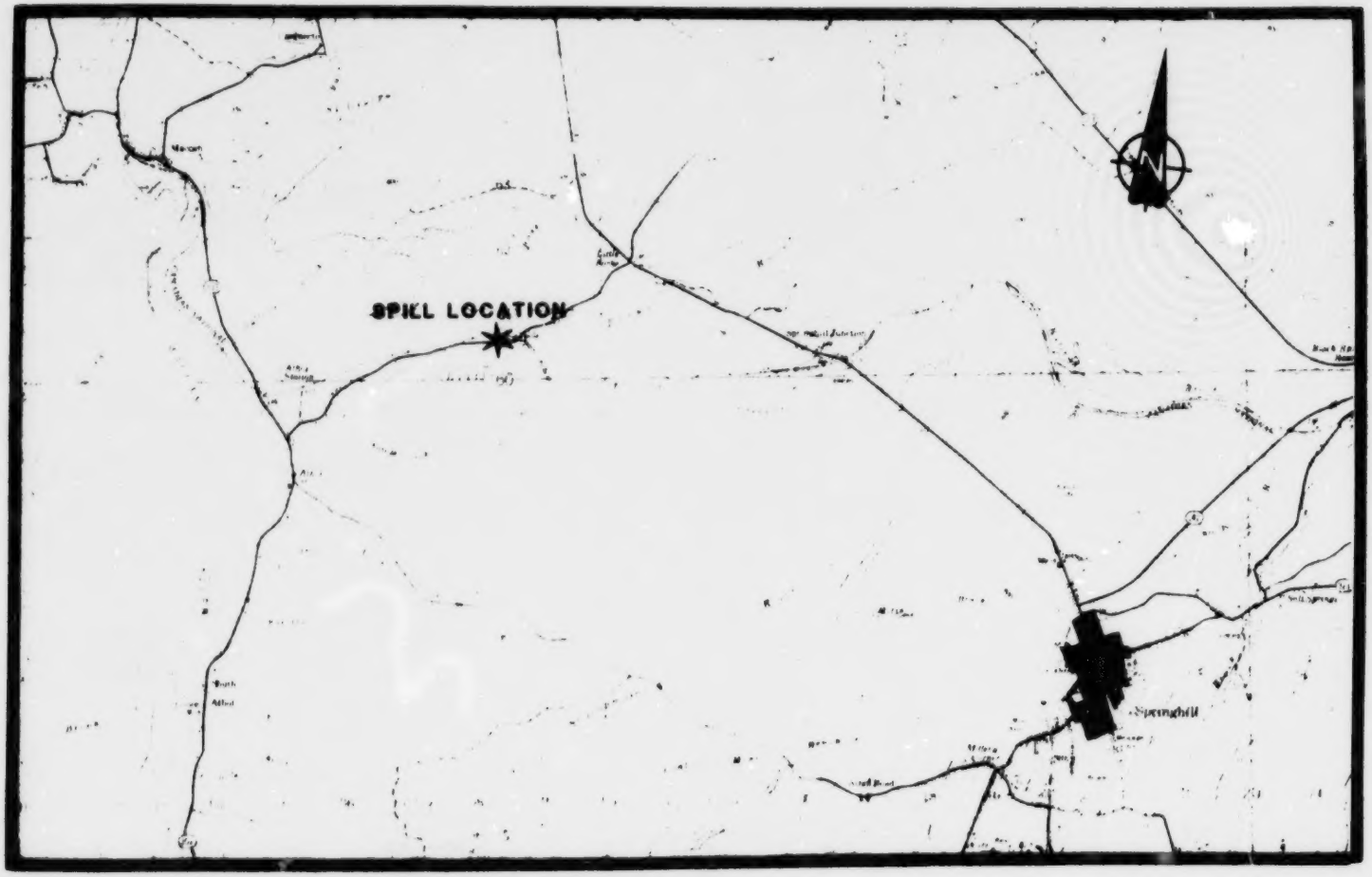
The acid pooled in a swale paralleling the south side of the tracks, and flowed downslope along three distinct paths (one major, two minor). Most of the spilled acid disappeared into a hole which opened up in the ground, flowing into an underground pit or cavity of unknown origin. Because of the highly fractured nature of the bedrock in the area, it is likely that most of the acid that reached the pit quickly found its way into the groundwater. To our knowledge, no adverse effects on groundwater were reported.

Overland flow of acid was fairly restricted. Although the spill occurred at the top of a slope, eyewitnesses from Environment Canada (R. Simmons, L. Tripp) indicated that the three rivulets of acid flowed only part way down the slope. No acid reached the ditch on the north slide of the highway at the bottom of the slope. A number of factors may have contributed to this:

1) The amount of acid flowing overland was greatly reduced because of the loss of liquid to the underground cavity.

2) The surficial materials on the slope were highly permeable.

3) Although it was early winter and the ground was lightly snow covered, the ground was not yet frozen. This was confirmed by members of the spill response team who indicated there was no frost in the ground when an emergency access road was bulldozed to the site.



LOCATION OF ACID SPILL
FIGURE 1

RECONSTRUCTION OF ACID SPILL

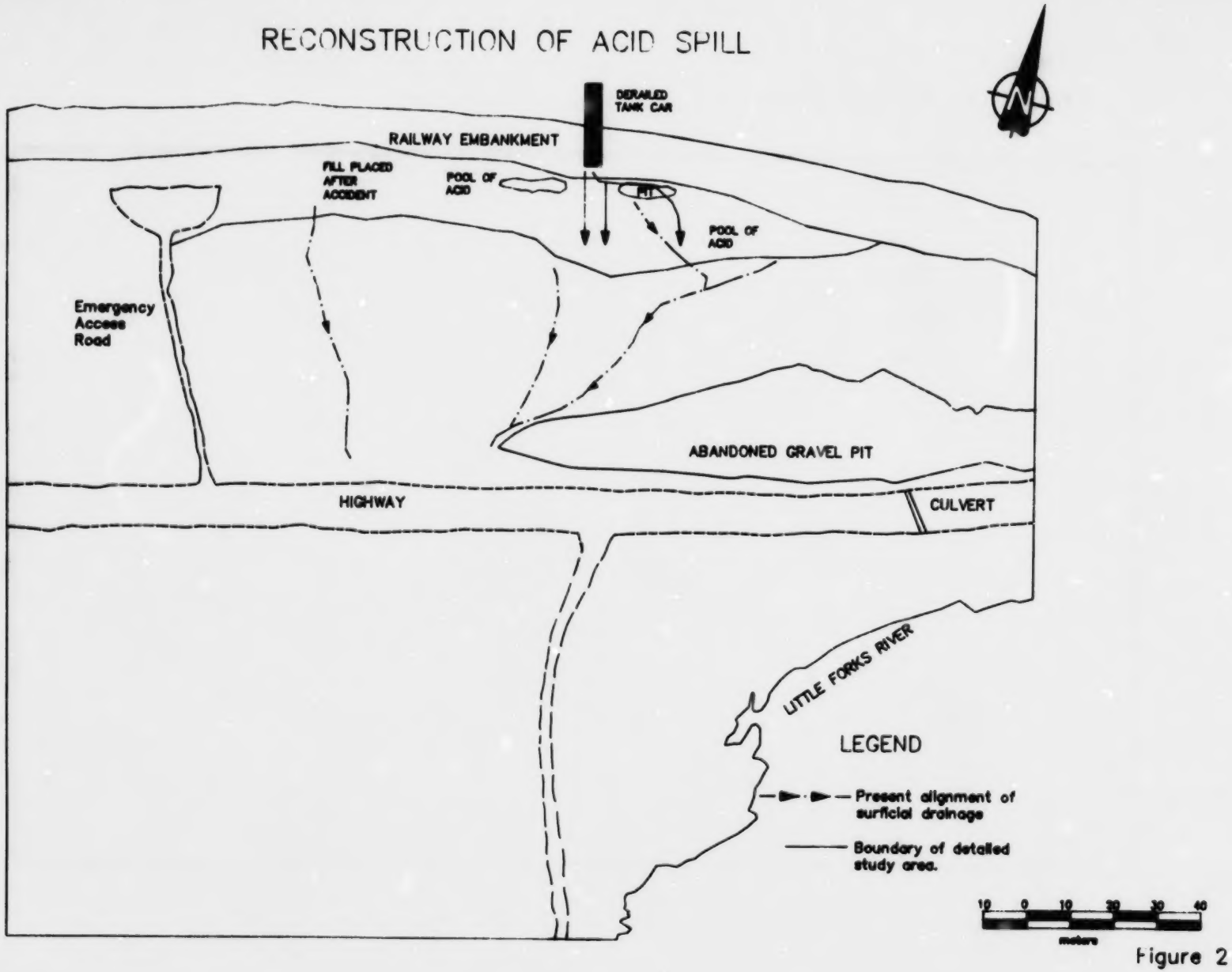


Figure 2

The Environment Canada report on the spill indicated that a CN employee and a local resident were injured as a result of stepping in a pool of acid. The owner of the land thought that these accidents had occurred at the highway ditch. However, conversations with L. Tripp, the author of Environment Canada's report on the spill, confirmed conclusively that the accidents occurred at the railside swale where acid had pooled immediately after the spill, and that no acid ever reached the roadside ditch.

After the derailment, the priority was to restore service on the mainline. The major area of activity was to the north of the railway right-of-way which could be accessed by a dirt road that joins the highway just east of the railway bridge spanning the highway and the Little Forks River. Removal of cars and railway repair activities resulted in considerable terrain disturbance north of the tracks.

No action was taken to neutralize the spilled acid until a truckload of sodium hydroxide arrived on site at 15:00 hours on December 14, 25 hours after the spill occurred. At that time an attempt was made to bulldoze a short access road from the highway to the spill site. This activity was halted when the bulldozer broke down. By the time the truckload of sodium hydroxide was pulled up to trackside the following day (December 15), almost two days has elapsed since the spill, the roadbed had been rebuilt and train service had been restored. Neutralization was done selectively where pockets of acid could still be reached. Sodium hydroxide was allowed to percolate through the new roadbed material to neutralize the acid underneath. Moreover, it is clear that significant amounts of sodium hydroxide were pumped into the cavity where much of the acid had flowed. (A solid block of sodium sulphate, the product of neutralizing sulphuric acid with sodim hydroxide, can still be seen in the pit to this day.)

The top of the slope where the spill occurred was severely impacted by physical disturbance associated with response to the spill. All of the natural vegetation was bulldozed and the site covered with up to 90 cm of sandy fill. Much of this fill remains almost barren of vegetation after

seven growing seasons, and thus constitutes the major long-term disturbance associated with the spill.

The direct effects of the spill itself are relatively subdued after seven growing seasons. The ground vegetation in acidized areas is superficially indistinguishable from unaffected areas. Shrubs are reinvading areas where acid-induced shrub mortality was high. The main signs of a previous spill are the standing remains of dead shrubs.

3. THE STUDY AREA

An area of some 3.5 hectares between the railway embankment where the spill occurred and the Little Forks River was selected as the study area (Figure 3). The area was selected to be sufficiently large to represent the maximum potential zone of influence of the spill. A 0.3 ha portion of this area, lying within or directly adjacent to the zone of observable effects was selected for detailed study.

The study area comprises portions of an ancient glaciofluvial terrace and the modern floodplain of the Little Forks River. The railway follows the top of the terrace, while the highway to the south of it follows the base of the terrace slope at the edge of the floodplain.

The highway acts as a barrier to natural drainage of the slope. Runoff is intercepted by a ditch on the north side of the highway and flows eastward before passing through a culvert under the highway to the Little Forks River.

Surficial materials consist of generally well drained glaciofluvial sands and gravels on the slope north of the highway and generally well drained sands and gravels of more recent fluvial origin in the bottomland south of the highway. Pockets of imperfectly drained soils exist on both sides of the highway, but occupy a significantly larger proportion of the total area on the more recent floodplain deposits south of the highway.

The study area has experienced numerous man-made disturbances, including forest clearing and tilling of the soil on both the slope and the bottomland, construction of the railway and the highway, and the working of a large gravel pit north of the highway at the eastern edge of the study area. Judging from the size of trees occupying the site of the large gravel pit, it would appear that it has not been worked since the turn of the century.

STUDY AREA

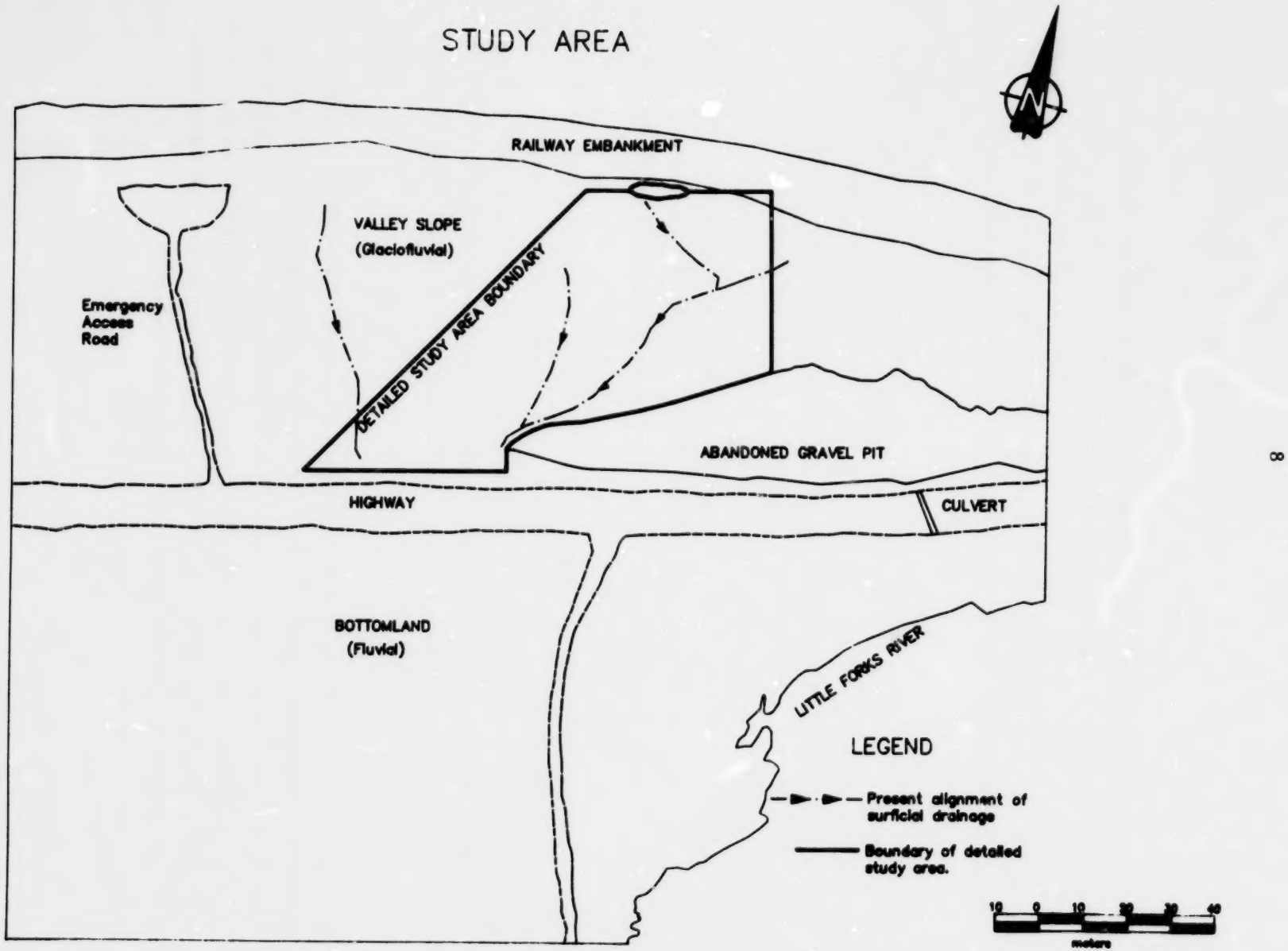


Figure 3

Other evidence of human use and habitation includes the remains of a building foundation at the western edge of the study area. The building supported by this foundation may have been a farmstead or railway structure, or may even have been associated with the past gravel extraction operations. The railside pit into which much of the acid disappeared may also be the remains of a building foundation, perhaps for some railway-related structure.

The most recent disturbances to the site are the construction of the temporary access road to the spill site, the placement of fill in the area of the acid spill and the excavation of gravel from a small pit at the western edge of the study area, north of the highway.

The entire study area is in the process of reverting from agricultural land to a forest community. The abandonment of agricultural land use has taken place in stages, first on the slopes north of the highway and more recently on the bottomlands south of the highway. The stage of succession to forest cover therefore varies significantly over the study area.

The non-homogeneous conditions of surficial geology, soils and vegetation, and the past history of multiple site disturbances tend to add somewhat to the difficulty in interpreting a single disturbance event such as an acid spill.

4. THE STUDY PROGRAM

Field data were collected at two levels of detail:

1) An overview level to provide the context for the area affected by the spill.

2) A high resolution level to document relatively localized variations in effects within the main area of impact.

Data collected at an overview level of detail included soils profile descriptions and pH measurements in the total study area and vegetation mapping of the portion of the study area between the railway and the highway.

High resolution data, covering a wide range of biological and chemical parameters, was collected within quadrats or cells placed at regular intervals in the main area of spill impacts (Figure 4). Identically formatted sets of data on the shrubs, ground vegetation, the soil profile and soil chemistry were collected in each of these quadrats.

These data were used to identify spill-induced changes in vegetation and soils, to estimate the areal extent of such changes and to study the process of recovery of the site.

4.1 VEGETATION STUDIES

The vegetation between the railway tracks and the highway, covering an area 220 m x 60 m, was mapped by reference to a 20 m x 20 m grid laid out on the ground at the start of the field program (Recent aerial photos, although flown in 1985, were not available at the time of the field work). The portion of the mapped area affected by the acid spill was then identified by a combination of eyewitness accounts and evidence of physical disturbance and/or shrub mortality.

SAMPLING QUADRATS IN DETAILED STUDY AREA

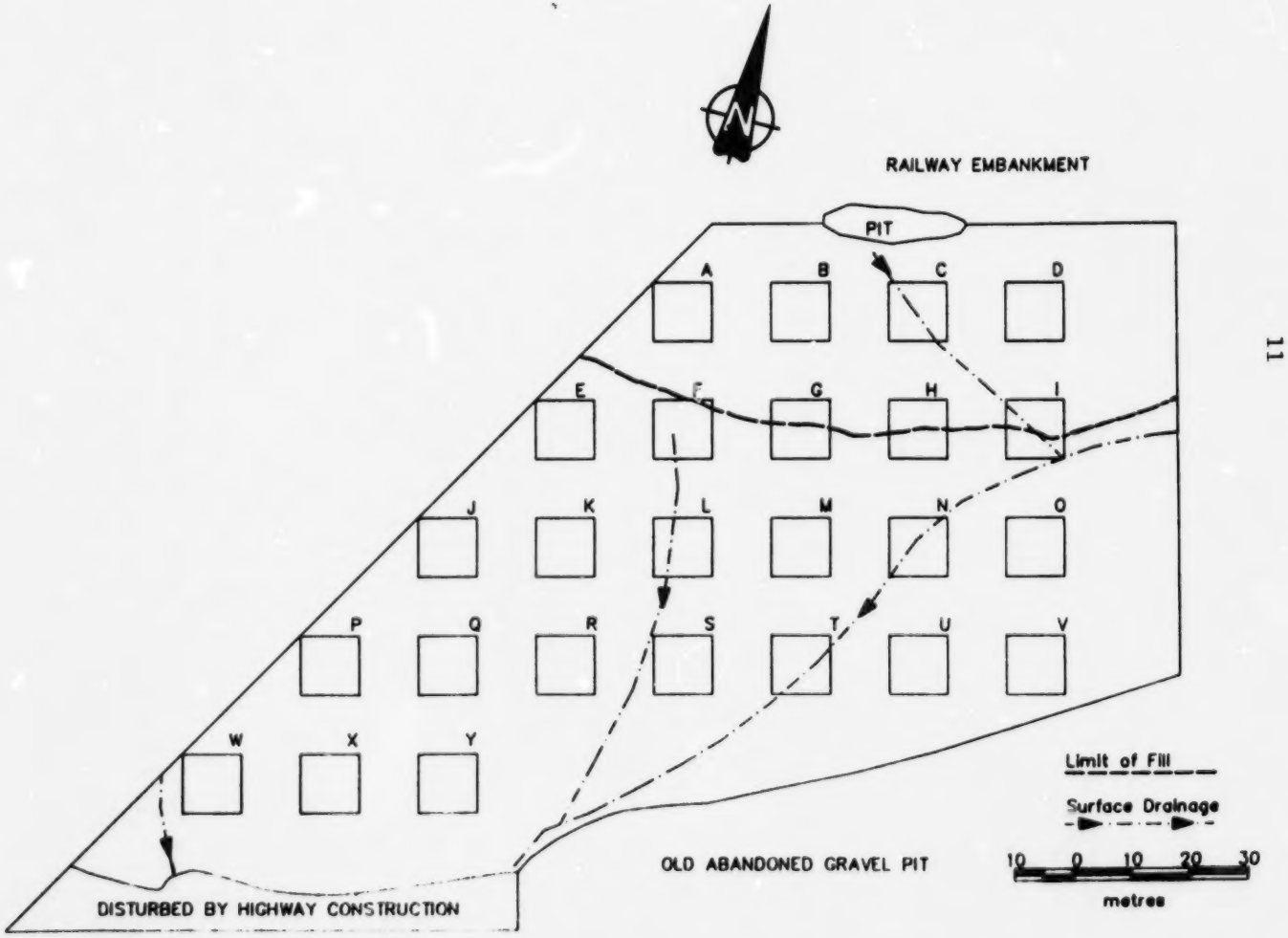


Figure 4

This smaller area, within which subsequent detailed work was concentrated, was roughly 0.3 ha in size. Within this area, twenty-five 5 m x 5 m quadrats were established at a regular spacing of 10 m, centre to centre, for sampling of the shrub layer of vegetation. Within each quadrat, ten 1 m x 1 m subquadrats were established randomly to sample the ground vegetation.

4.1.1 Shrubs

Within each 5m x 5m quadrat, all living or dead shrubs (woody plants more than 1.5m at maturity) were identified to species and the diameters of their stems measured at 20 cm above ground level.

Raw shrub data were grouped according to species. The stem density of each species in each quadrat (calculated separately for living and dead stems) was expressed as stems/ha. These were summed to give total stem density/quadrat. Stem basal area was calculated using the formula for the area of a circle (Πr^2). Each diameter measurement for a particular quadrat was transformed using this formula and summed by species. The totals for each species were summed to give the total basal area per quadrat. Basal area was expressed as m^2 of bole surface area per hectare.

4.1.2 Ground Vegetation

Within each 5m x 5m quadrat, ten 1m x 1m subquadrats were randomly selected, and all ground vegetation species (herbaceous or woody plants less than 1.5m high at maturity) found inside of them identified. The abundance of each species was determined by visual estimate of the species' percentage contribution to ground cover.

Matrices were prepared for each of the twenty-five 5m x 5m quadrats, showing the percentage contribution to ground cover of each species found within each of the ten 1m x 1m subquadrats sampled. The mean, standard deviation and coefficient of variation were calculated for each species within the matrix. In addition, the relative cover for each species within each 5m x 5m quadrat was calculated.

4.1.3 Shrub Growth Ring Studies

After all non-destructive sampling had been completed, a number of shrubs from each 5m x 5m quadrat were harvested, and discs were cut from their boles at approximately 20 cm above ground level. The annual rings of these discs were measured and counted so that their growth rates and age could be determined. Hawthorn (Crataegus macrosperma) was found to be the most common shrub species on the site. Consequently, the ten largest Hawthorn individuals within each 5m x 5m quadrat were harvested. Hawthorn, however, was not present in some quadrats, or fewer than ten Hawthorns were available. In these cases, the ten largest individuals of the most common shrub species in the quadrat were harvested in addition to all Hawthorns present. Each shrub disc was marked with three lines running radically from the centre of the first growth ring to the last growth ring. These lines were separated by a 120° angle. Measurements of annual ring growth were begun at the most recent year's growth and continued to the first year's growth. This process was repeated for each of the lines.

The mean, standard deviation and coefficient of variation of each year's growth were calculated. The mean ring widths of the replicates were plotted against time in order to observe any changes in growth rate associated with the acid spill. Comparisons of growth rates for acidified and undisturbed areas were carried out using the ring width data for Hawthorns. Comparisons were made using three methods. In the first method, the mean growth rates for all Hawthorns within each 5m x 5m quadrat were calculated for each of the last five years. Each quadrat was classified as acidified or undisturbed and mean values for the quadrats within each of the classifications were calculated. T-tests were utilized to determine whether differences in the means of acidified and undisturbed quadrats were statistically significant. The second method was similar to the previous one except that only Hawthorns between four and seven years of age had their ring widths compared. The third method involved comparing the growth rates of the first five years of growth. The first five years of growth for shrubs originating after the acid spill would potentially be affected by the chemical contaminants while the first five

years of surviving trees (older than age 5 before the incident) and unaffected trees would be free of this influence. This method and the previous one minimized variation in the data caused by the effect of age on the growth rates of shrubs. For this method, calculations of means within quadrats and collective means for acidified and undisturbed quadrats were made in the same manner as the first method.

4.2 SOILS STUDIES

4.2.1 Soils Mapping

A detailed soils map of the entire study area was prepared using soil profile data obtained from 66 soil observation pits. Forty-one of these observation pits were spread throughout the overall study area and 25 additional pits were located in each of the 5m x 5m quadrants in the detailed study area. Thus the resolution of the soils map is somewhat enhanced in the latter zone. The location of the soils pits are shown in Figure 5.

Soils mapping was done on a stereoscopic pair of existing colour aerial photos flown on July 1, 1975 at a scale of 1:10,000 and enlarged to a scale of 1:1,041. Soils were classified by the Canadian System of Soil Classification, using the soils series names commonly used in Cumberland County, Nova Scotia.

4.2.2 pH Measurements

Measurements of pH were taken at the A, B and C horizons in 32 of the 41 soil pits dug for the soils map of the total study area. In addition, a pH measurement of a composite soil sample taken from different levels of the rhizosphere (zone of plant root growth) was taken at each of the 25 pits dug in the detailed study area. A pH map of average soil pH, covering the same area as the soils map, was then prepared. This map, like the soils maps, has enhanced resolution in the detailed study area.

Measurements of pH were performed in the laboratory, using the Calcium Chloride Method as described in Sheldrick (1984).

SOIL OBSERVATION AND SAMPLING LOCATIONS

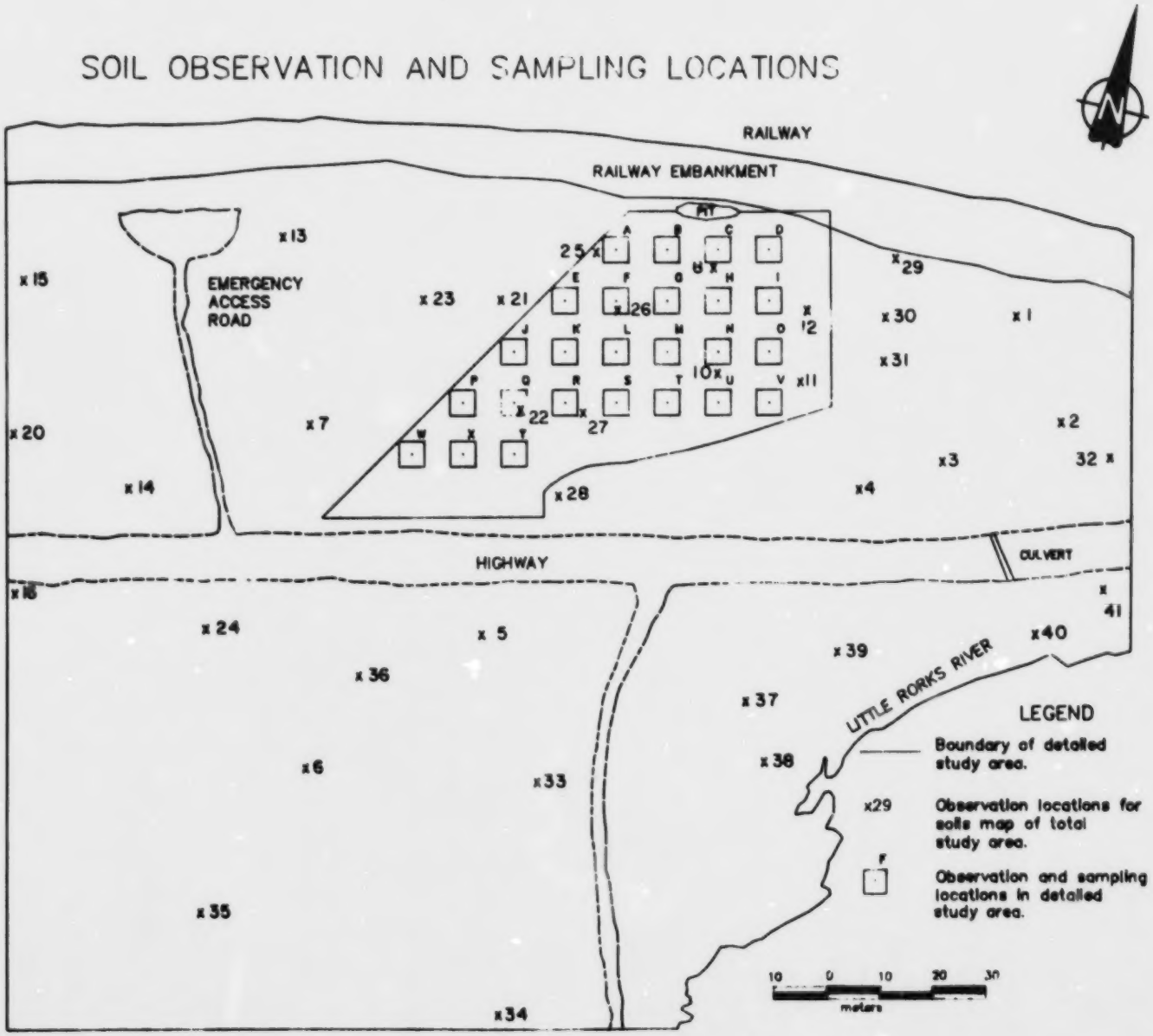


Figure 5

4.2.3 Soil Chemistry

Samples, representing average conditions in the rhizosphere, were taken from each of the 25 pits dug in the detailed study area. The following parameters were measured:

1) Exchangeable Acidity (Barium Chloride - Triethanolamine method) as described in Miller and Keeney (1982).

2) Calcium, Magnesium, Potassium, Sodium and Aluminum analyzed by inductively coupled plasma atomic absorption spectroscopy, after extraction by the Extractable Ammonium Acetate Method in Sheldrick (1984).

3) Electricl Conductivity as per Sheldrick (1984).

4) Sulphate Sulphur (Turbidimetric Method - Potassium Phosphate Extractable) as per Fox et al. (1964).

4.3 MULTIVARIATE ANALYSIS

The vegetation and soils data collected within the twenty-five 5m x 5m quadrats in the detailed study area were subjected to analysis using a parametric statistical method known as cluster analysis, which groups cases by their degree of similarity. Because such methods assume a normal distribution, with data clustered symetrically around a mean, the data were subjected to appropriate transforming functions. The methods of transforming the data and performing the cluster analysis are described at some length in Appendix 1.

4.4 LITERATURE SEARCH

A comprehensive computerized literature search was undertaken to identify any relevant publications concerning sulphuric acid and the potential effects resulting from accidental spills. The following literature data bases were accessed:

- Chemical Abstracts
- Pollution abstracts
- National Technical Information Service
- Biological Abstracts
- Transportation Index
- Enviroline
- Environmental Bibliography

Approximately 25 abstracts were identified as being potentially relevant. Copies of these documents were requested from various library holdings, identified through the data search and were examined at our office.

Specific information pertaining to sulphuric acid spills was also requested from the Canadian Transport Commission (Railway Transport Committee) as well as Transport Canada (Transport Dangerous Goods Directorate). A listing of all accidents/incidents reported by the railways under the jurisdiction of the CTC was outlined for the period January 1982 to August 1985.

Finally, government regulatory agencies responsible for investigating and preparing reports on specific spill events were contacted regarding existing accident reports. Five spill investigation reports were examined in detail.

5. RESULTS

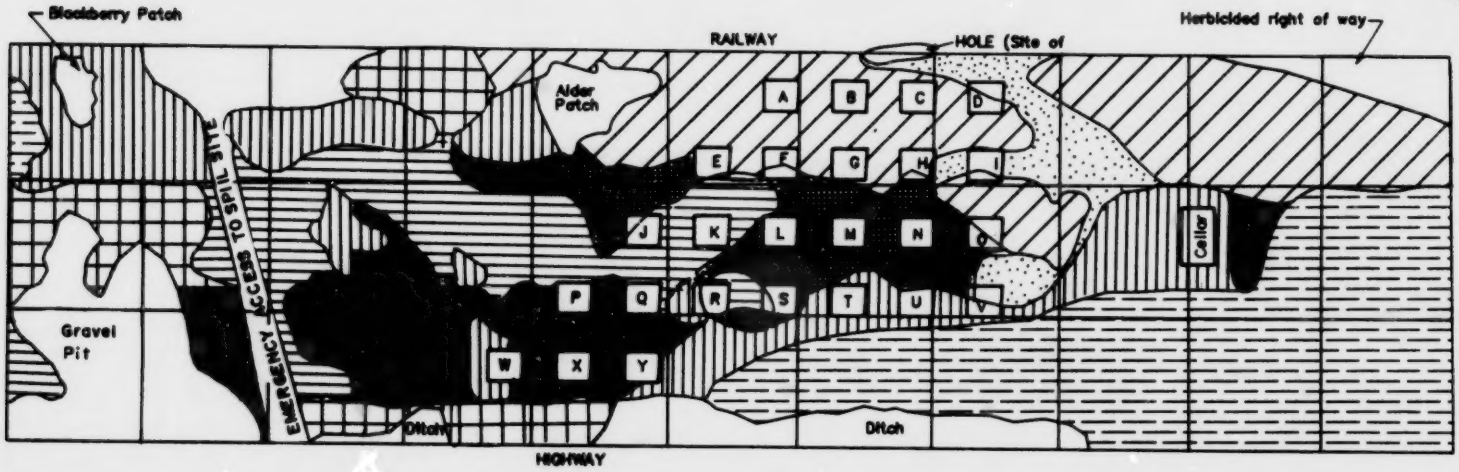
5.1 VEGETATION OF THE SITE - AN OVERVIEW

Eight major plant communities were characterized during the vegetation survey of the 220 x 60m portion of the study area between the railway and the highway. The distribution of these communities is shown in Figure 6. Brief descriptions of the dominant species of each class of vegetation (shrubs, ground vegetation and trees) are provided in Table 1. Complete lists of the shrubs and ground vegetation species found in the study are are presented in Tables 2 and 3. The mapped area consists of abandoned agricultural land in various stages of secondary succession. Four of the mapped communities represent distinctive stages in the eventual establishment of a mature forest community. An abandoned pasture community represents the early stage in this successional sequence. This stage is followed by a Hardhack-Sweetfern community as shrubs invade the pasture. Taller shrubs and low trees such as Hawthorn and Black Cherry begin to displace the low shrubs as the successional process continues. Eventually tree species begin to displace the shrubs, forming an open woodland community. At this stage, Black Cherry and Trembling Aspen dominate. Succession will continue in this woodland and eventually these tree species will be replaced by more shade tolerant ones. The influence of humans on the forecast succession of this area is apparent from the presence of two tree species in the open woodland community, Apple (Pyrus malus) and Balsam Poplar (Populus balsamifera), which are not native to Nova Scotia.

The remaining plant comunities of the mapped are appear to be associated with disturbances occurring during succession. A Sweetfern community occurs mainly on exposed mineral soil in ditches or where fill has been laid down. Goldenrod and Bentgrass-Goldenrod communities are also associated with exposed mineral soil. The Goldenrod community tends to be associated with thicker layers of fill than the Bentgrass-Goldenrod community. These two communities were found in the parts of the study area that had been subjected to both

VEGETATION MAP

(NORTH OF HIGHWAY AND SOUTH OF RAILWAY)



LEGEND

- OPEN WOODLAND
- HAWTHORN – BLACK CHERRY COMMUNITY
- HARDHACK – ALDER COMMUNITY
- HARDHACK – SWEETFERN COMMUNITY
- GOLDENROD COMMUNITY
- BENTGRASS – GOLDENROD COMMUNITY
- ABANDONED PASTURE
- SWEETFERN COMMUNITY

10 0 10 20 30
meters

Figure 6

TABLE 1 Description of Mapped Plant Communities

Community	Tree Layer		Shrub Layer		Ground Layer		Comments
Abandoned Pasture					Bentgrass White Goldenrod	(Agrostis tenuis) (Solidago bicolor)	
Hardhack - Sweetfern			Hardhack Sweetfern Blackberry	(Spirea latifolia) (Comptonia peregrina) (Rubus recurvicaulis)	Bentgrass Hair Fescue White Goldenrod	(Agrostis tenuis) (Festuca capillata) (Solidago bicolor)	Initial shrub invasion of abandoned pasture. No standing dead trees, suggesting it escaped acid disturbance.
Hawthorn - Black Cherry			Hawthorn Black Cherry Hardhack	(Crataegus macrosperma) (Prunus serotina) (Spirea latifolia)	Tall White Aster Rough Goldenrod	(Aster umbellatus) (Solidago rugosa)	Well established shrub community that appears to have escaped acid disturbance.
Open Woodland	Black Cherry Trembling Aspen Apple	(Prunus serotina) (Populus tremuloides) (Pyrus malus)	Chokecherry Hawthorn Wild Raspberry	(Prunus virginiana) (Crataegus macrosperma) (Rubus strigosus)	Canada Goldenrod Rough Goldenrod Tall White Aster	(Solidago canadensis) (Solidago rugosa) (Aster umbellatus)	
Sweetfern			Sweetfern Hardhack Blackberry	(Comptonia peregrina) (Spirea latifolia) (Rubus recurvicaulis)			Invades ditches and other areas of exposed mineral soil.
Goldenrod					Rough Goldenrod Canada Goldenrod	(Solidago rugosa) (Solidago canadensis) (Solidago graminifolia)	Community on thick fills in areas disturbed both physically and chemically by acid spill.
Bentgrass - Goldenrod					Bentgrass Rough Goldenrod Canada Goldenrod	(Agrostis tenuis) (Solidago rugosa) (Solidago graminifolia)	Community on fills in areas disturbed both physically and chemically by acid spill; fill layer typically thinner than on sites occupied by Goldenrod community.
Hardhack - Alder			Hardhack Downy Alder Blackberry	(Spirea latifolia) (Alnus crispa) (Rubus recurvicaulis)	Rough Goldenrod Tall White Aster Canada Goldenrod	(Solidago rugosa) (Aster umbellatus) (Solidago canadensis)	Community of recent origin. Presence of standing dea shrubs. This community is found on sites that were occupied by the Hawthorn Black Cherry community prior to the disturbance of the acid spill.

TABLE 2 Species List for Shrubs

Scientific Name	Common Name
Alnus crispa	Downy Alder
Amelanchier laevis	Shadbush
Amelanchier lucida	Bilberry
Betula populifolia	Gray Birch
Cornus alternifolia	Alternatie-leaved Dogwood
Crataegus macrosperma	Hawthorn
Picea glauca	White Spruce
Populus tremuloides	Trembling Aspen
Prunus pensylvanica	Pin Cherry
Prunus scrotina	Black Cherry
Prunus virginiana	Chokecherry
Pyrus malus	Apple
Salix Bebbiana	Beaked Willow
Viburnum cassinoides	Witherod
Viburnum triloba	Highbush Cranberry

TABLE 3 Species List for Ground Vegetation

Scientific Name	Common Name	Scientific Name	Common Name
Achillea lanulosa	Yarrow	Leontondon autumnalis	Fall Dandelion
Agropyron repens	Quack Grass	Oenothera sp.	Evening Primrose
Agrostis alba	Redtop	Panicum lanuginosum	Panic Grass
Agrostis tenuis	Bentgrass	Panicum sp.	Panic Grass
Anaphalis margarataceae	Pearly Everlasting	Phleum pratensis	Timothy
Antennaria neodioica	Everlasting	Plantago lanceolata	English Plantain
Aralia hispida	Bristly Aralia	Poa compressa	Canada Bluegrass
Aronia prunifolia	Chokeberry	Poa palustris	Meadow Grass
Aster cordifolius	Heart-leaved Aster	Poa pratensis	Kentucky Bluegrass
Aster lateriflorus	Calico Aster	Potentilla canadensis	Dwarf Cinquefoil
Aster umbellatus	Tall White Aster	Potentilla recta	Rough-fruited Cinquefoil
Carex conoidea	Sedge	Prenanthes trifoliata	Lion's Paw
Carex debilis	Sedge	Rosa carolina	Pasture Rose
Carex Hougtonii	Sedge	Rubus allegheniensis	Blackberry
Carex projecta	Sedge	Rubus recurvicaulis	Blackberry
Carex scoparia	Sedge	Rubus strigosus	Wild Raspberry
Carex spp.	Sedge	Rubus vermontanus	Blackberry
Chrysanthemum leucanthemum	Ox-eye Daisy	Rumex acetosella	Sheep Sorrel
Circium arvense	Canada Thistle	Scirpus cyperinus	Bulrush
Comptonia peregrina	Sweetfern	Sisyrinchium montanum	Blue-eyed Grass
Danthonia spicata	Poverty Grass	Solidago bicolor	White Goldenrod
Dennstaedtia punctilobula	Hay-scented Fern	Solidago canadensis	Canada Goldenrod
Dryopteris spinulosa	Wood Fern	Solidago graminifolia	Narrow-leaved Goldenrod
Erigeron annuus	Daisy Fleabane	Solidago rugosa	Rough Goldenrod
Festuca capillata	Hair Fescue	Spartina pectinata	Broadleaf
Festuca rubra	Red Fescue	Spiraea latifolia	Hardhack
Fragaria virginiana	Wild Strawberry	Spiraea tomentosa	Steeplebush
Geum macrophyllum	Large-leaved Avens	Vaccinium angustifolium	Blueberry
Hieracium aurantiacum	Orange Hawkweed	Vaccinium myrtilloides	Canada Blueberry
Hieracium Pilosella	Mouse-ear Hawkweed	Veronica officinalis	Common Speedwell
Hypericum perfoliatum	Common St.John's Wart	Vicia cracca	Tufted Vetch
Impatiens sp.	Touch-me-not	Viola incognita	White Violet
Juncus effusus	Soft Rush	Viola septentrionalis	Northern Blue Violet
Juncus tenuis	Rush		Cushion Moss
Lactuca canadensis	Wild Lettuce		Feather Moss

chemical and physical disturbance. A Hardhack-Alder community was generally associated with areas of standing dead stems, suggesting that is was the result of chemical disturbance.

The pattern of quadrats established to study the acid spill was centered squarely on the largest area of Hardhack-Alder vegetation. However, an additional area of Hardhack-Alder mapped on the western edge of the study area was missed by the sampling grid. This suggests that the effects of the spill extended further westward than was first apparent from our attempts to reconstruct the spill location from the account of an eyewitness who accompanied us prior to our staking out the quadrats. The shortness of the remaining field season necessitated a simultaneous program of vegetation mapping, gathering of vegetation data and gathering of soils data, which left no room for preliminary analysis of data and adjustments to the field program.

5.2 EVIDENCE OF PETURBATION OF THE VEGETATION

5.2.1 Comparison of Shrub Ages

Mean ages of the ten largest shrubs in each quadrat are presented in Figure 7. Shrubs growing on quadrats A, B, C and I were quite young, with mean ages ranging from 2.1 to 3.8 years, suggesting recent regeneration. This area was covered with a layer of fill after the acid spill and was, therefore, disturbed both chemically and physically. It is described as the fill zone.

Mean ages of shrubs on quadrats E, F, G, H, L and S ranged from 4.4 to 6.6 years, suggesting that this area was subjected to disturbance, but began to regenerate within a year or two after the spill. Examination of this area on aerial photographs taken before the acid spill revealed it to be previously occupied by fairly tall shrubs. Had these shrubs survived, their mean ages would have been much greater than presently observed. Apparently, all shrubs in this area were killed by the acid spill or subsequent neutralization efforts. Mean ages of shrubs on quadrats M, N and O ranged in age from 11.6

MEAN AGES OF SHRUBS IN THE 5mx5m QUADRATS.

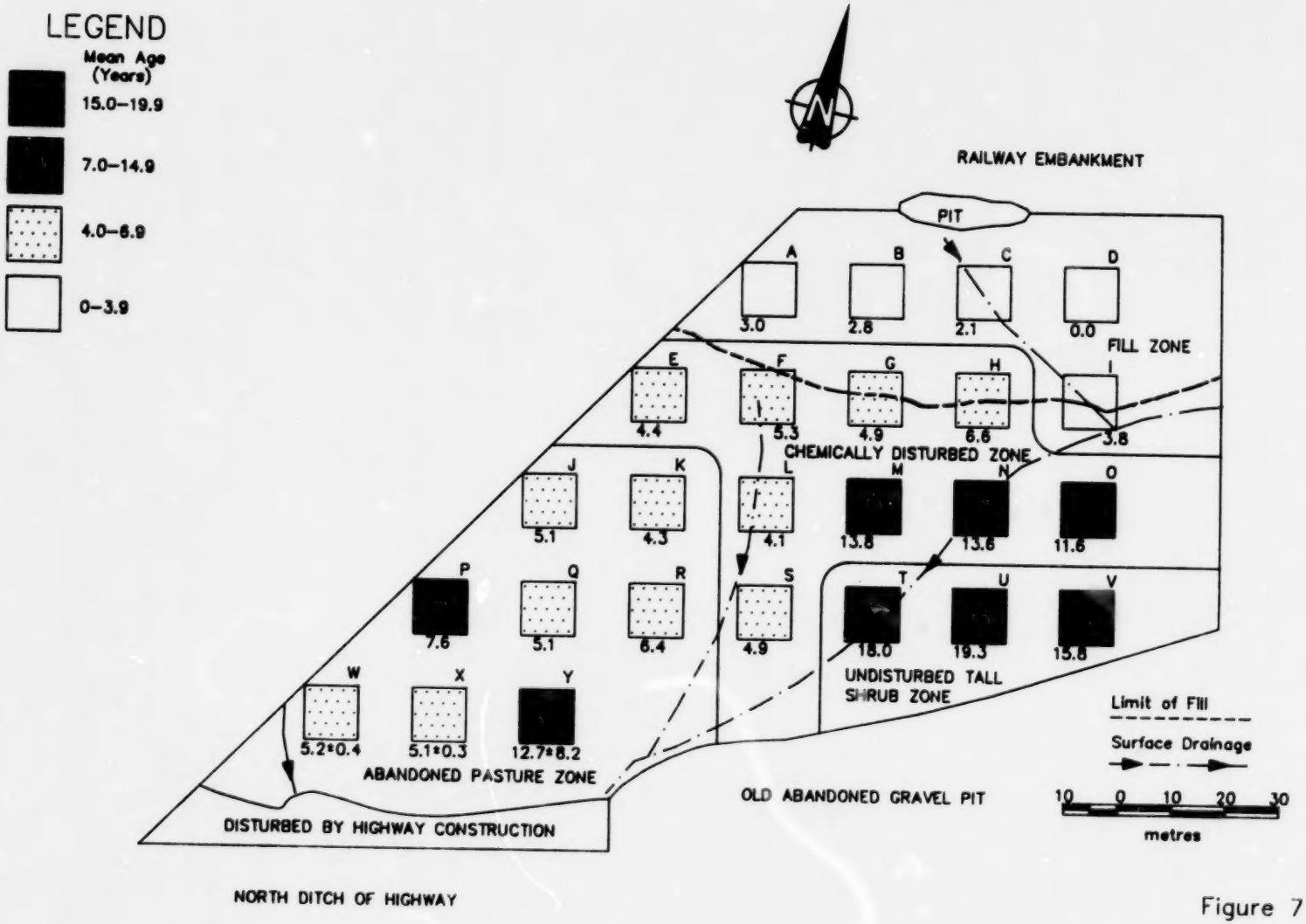


Figure 7

to 13.8 years, indicating that some shrubs in this area survived the acid spill, although a number of standing dead shrubs in these quadrats attest to some spill-related damage. The area encompassing quadrats E, F, G, H, L, M, N, O and S is described as the chemically disturbed zone.

Quadrats T, U and V represent an area which appeared to have escaped both physical and chemical disturbance. The mean ages of shrubs on these quadrats ranged from 15.8 to 19.3 years of age, the highest values of any quadrats in the study area. (These shrub ages compare very well to two control plots established to the west of the spill site which had mean ages of 16.0 to 17.2 years). This area has been called the undisturbed tall shrub zone.

Quadrats J, K, P, Q, R, W, X and Y also appear to have escaped contamination. However, this was not confirmed by the mean ages of shrubs on these quadrats, which ranged from 5.1 to 12.7 years.

Analysis of aerial photographs for the area indicated that just prior to the spill, this area was open pasture occupied by a few scattered clumps of Hawthorn. Therefore, the general lack of shrubs over 7 years of age need not indicate that this area was disturbed during and acid spill. Indeed, the projected flow paths for the acid avoid all of these quadrats. This area was defined as the abandoned pasture zone.

The locations of the four environmental zones described above are shown in Figure 8.

5.2.2 Comparison of Basal Areas of Shrubs

Differences in the distribution of shrub basal area over the study area also indicated that the acid spill and/or subsequent clean-up operations resulted in a major perturbation to the vegetation of the site. The aerial photographs indicate that much of the study area (with the exceptions of quadrats J, K, P, Q, R, W, X and Y) was occupied by a tall shrub community which would presently have total basal area values of shrubs exceeding $10 m^2/ha$ had it survived the acid spill. Total basal area values for shrubs living on quadrats A-I, L-O

THE FOUR ENVIRONMENTAL ZONES IN THE DETAILED STUDY AREA, AS INTERPRETED FROM SHRUB DATA.

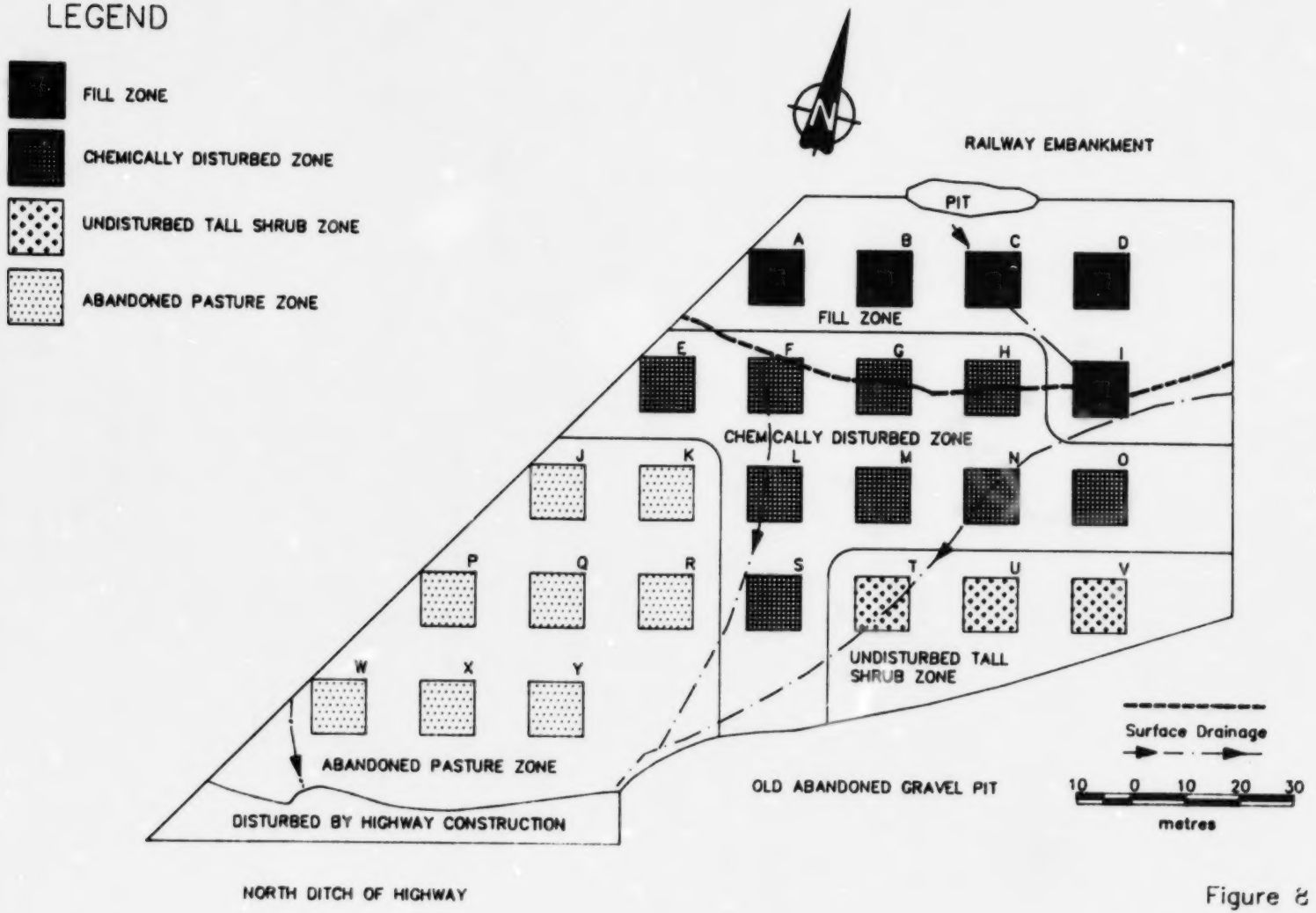


Figure 8

and S were under this level, suggesting that much of the shrub vegetation in this area had been killed. Figure 9 shows that total basal area tended to increase from north to south as the intensity of disturbance decreased. Quadrats A-D and I were located in the fill zone and have the lowest total basal area values for shrubs. Quadrats E, G, H and O were located at the interface between the chemically disturbed zone and the fill zone. Shrubs on these quadrats had somewhat higher total basal area values, suggesting a more rapid recovery after disturbance. Shrubs on quadrats F, L, M, N and S which were found within the zone experiencing chemical but not physical disturbance, had total basal area values ranging from 5.68 to 11.29m^2/ha, suggesting substantial recovery from spill-induced stresses. The undisturbed tall shrub zone (quadrats T, U, V) apparently suffered few acute effects from the spill; shrubs basal area values for this zone are the highest of all the quadrats.

5.2.3 Shrub Growth Trends and Rates

Growth trends of shrubs in the study area were remarkable consistent, thereby producing an excellent source of information on the impact of the acid spill and cleanup measures on the growth of these plants. The general trends of growth rates over time as related to the acid spill were categorized by four distinct patterns which are illustrated by the plots of growth rate versus time provided in Figure 10.

1) Growth Trend 1. All shrubs which had begun to grow after the date of the acid spill were included in this category. Large numbers of shrubs of this type in conjunction with standing dead trees would almost certainly indicate the occurrence of extensive mortality associated with the acid spill or the cleanup operation.

2) Growth Trend 2. Shrubs exhibiting this growth trend survived the acid spill but had their growth rates markedly reduced by the damage they had sustained. Initial decreases in growth were associated with the date of the acid spill. Only short-term growth declines were noted in this study. Growth was markedly reduced during the first season or two after the spill, but typically experienced substantial recovery in subsequent years.

BASAL AREA OF SHRUBS (PER HECTARE) IN 5mx5m QUQDRATS.

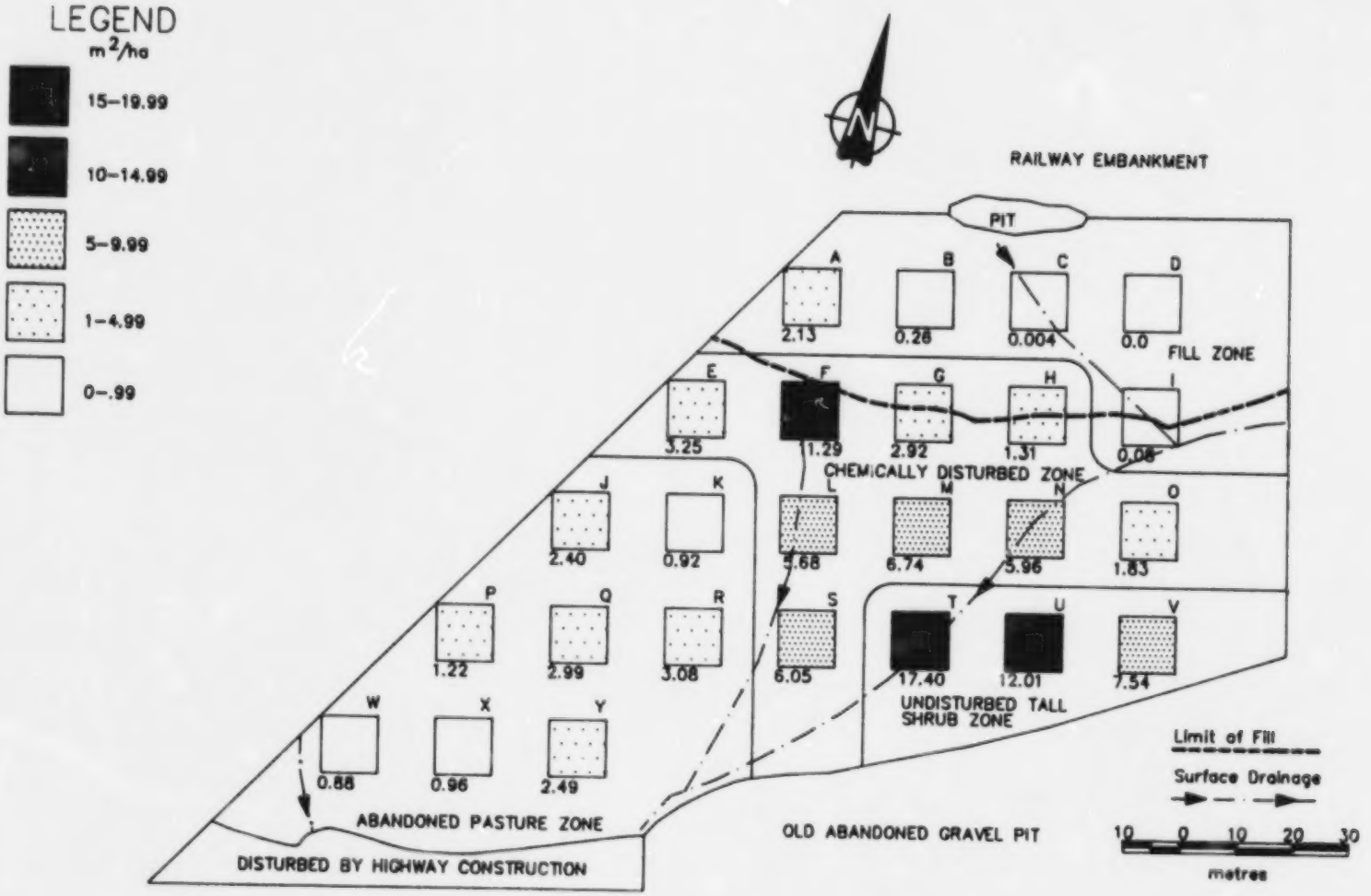
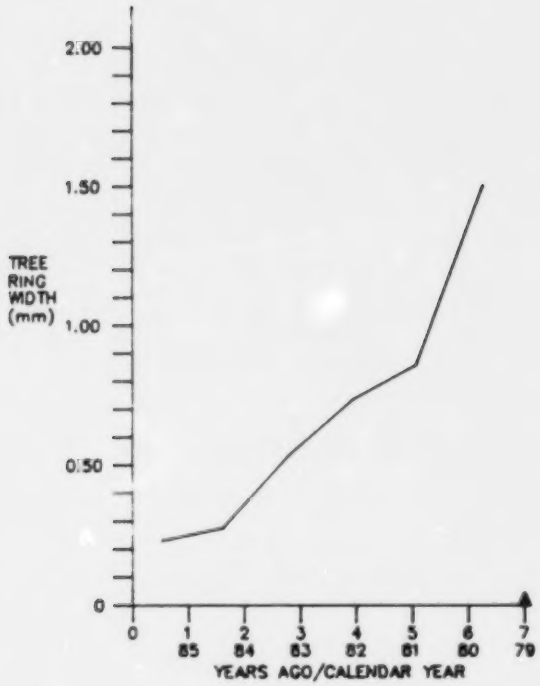
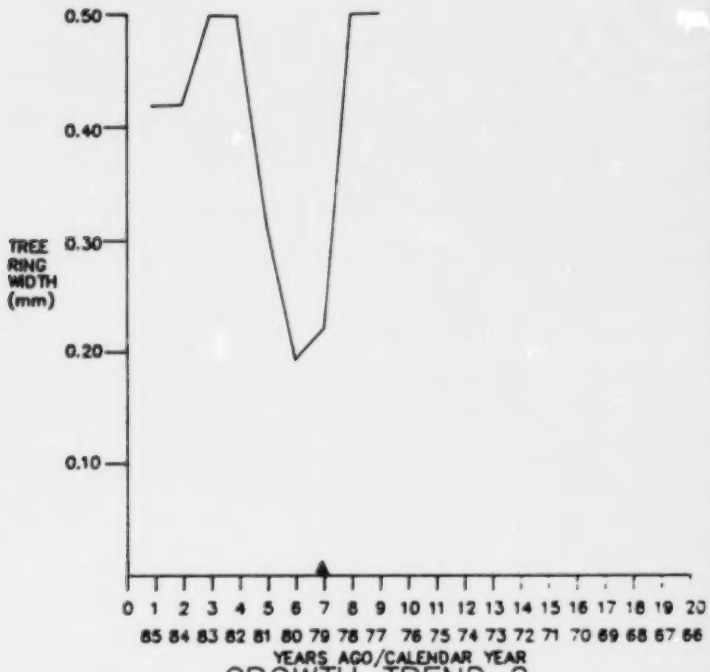


Figure 9

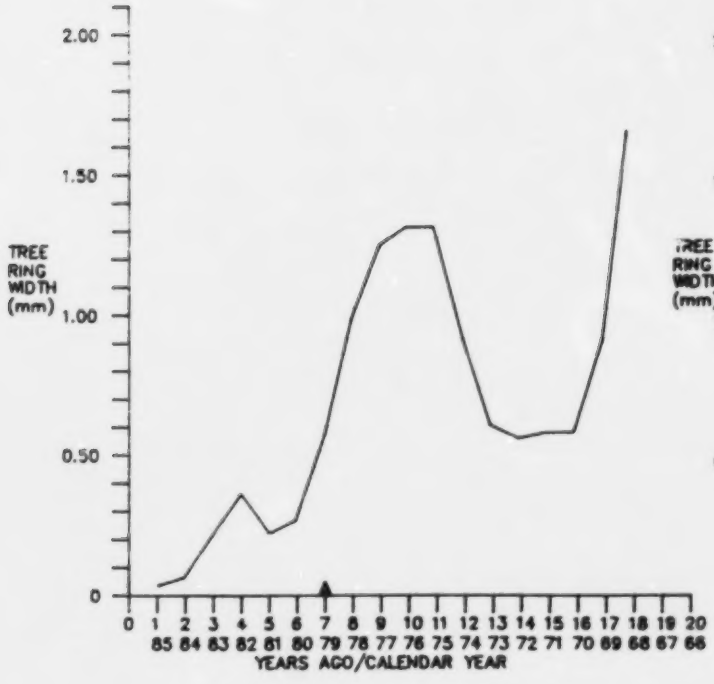
GROWTH TRENDS OF HAWTHORN



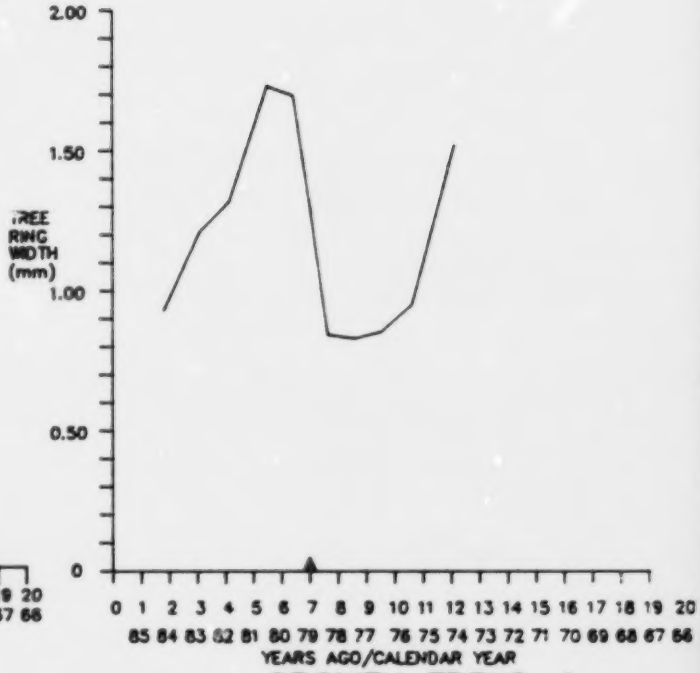
GROWTH TREND 1
(SAMPLE 23 FROM QUADRAT M)



GROWTH TREND 2
(SAMPLE 14 FROM QUADRAT O)



GROWTH TREND 3
(SAMPLE 6 FROM QUADRAT T)



GROWTH TREND 4
(SAMPLE 1 FROM QUADRAT P)

NOTE: ▲ Denotes growing season following spill (summer of 1979)

Figure 10

3) Growth Trend 3. Shrubs exhibiting growth trend 3 survived the acid spill and exhibited no marked decline in growth associated with the date of the incident. Several reasons for this situation are possible:

   a) The shrubs may have been located in areas that escaped exposure to the acid or the base used to neutralize it.

   b) The acid may have percolated through the soil and flowed through the quadrats under the rooting zone of these shrubs.

   c) The shrubs may have been located on a high spot that remained above the level of acid percolation through the soil.

   d) The root systems of the shrubs may have been particularly shallow, thereby, avoiding the subsurface flow of acid.

4) Growth Trend 4. Some shrubs not only survived the acid spill but benefited from it as well. In these instances a marked increase in growth rate was associated with the date of the acid spill. This increase in growth rate was presumably associated with the removal of competing vegetation.

The relative frequencies of each of the growth trends within the quadrats are presented in Figure 11.

Quadrats exhibiting only growth trend 1 fell into two categories:

1) These from the fill zone and the chemically disturbed zones (quadrats A-G, I, L and S) which appear to have been invaded after the mature shrub vegetation was killed by the spill.

2) Those from the abandoned pasture zone (quadrats J, K, P, W and X) which appear to be simply experiencing a stage in old field succession, unrelated to the acid spill.

RELATIVE FREQUENCY OF FOUR SHRUB GROWTH TRENDS.

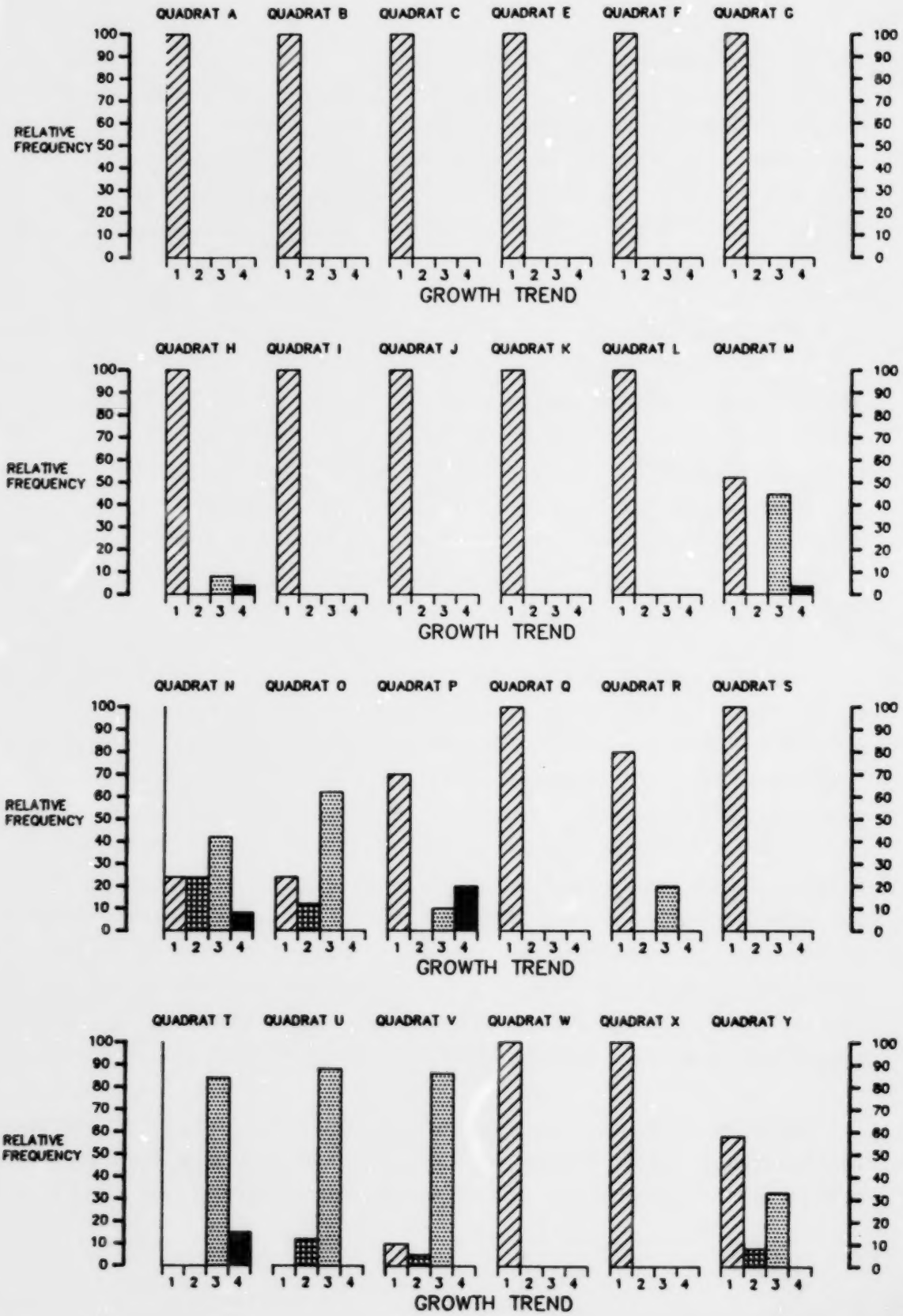


Figure 11

The remaining quadrats (H, M, N, O, P, R, T, U, Y) display various combinations of growth trends 1 to 4. Only five of these quadrats (N, O, U, V and Y) exhibit growth trend 2 (temporary growth retardation), and in all of these cases the relative frequency of shrubs displaying this growth trend is overshadowed by the relative frequency of shrubs displaying growth trend 3 (no effect). These results suggest that impact of the spill on the vegetation of these quadrats, which are concentrated in the southeast corner of the detailed study area, was quite light. Instances of some shrubs actually benefiting from the spill (growth pattern 4) were found in quadrats H, M, N, P and T. This pattern is always associated with growth pattern 3 (no effect) and in most cases also with growth pattern 1 (growth starting after the spill). Growth pattern 4 seems to be associated with quadrats whose vegetation was only partially affected by the spill, resulting in lessened competition for some of the unaffected survivors. The enhancement of growth of some shrubs in quadrat P, which lies well removed from area presumed to have been affected by acid, is not explained by the above mechanism. It is conceivable that it is simply an anomaly associated with a relatively small sample size.

In order to determine whether acidification of the site had caused long-term reductions in the growth rates of shrubs, comparisons were made of the growth rates of shrubs found in acidified and undisturbed quadrats. Comparisons were made within a single species, since interspecific differences in potential growth rates are common. Hawthorn (Crataegus macrosperma) was the only species which occurred with sufficient frequency to make these comparisons possible. Mean growth of Hawthorn for each of the last 5 years is presented for both undisturbed and acidified quadrats in Table 4. The data reveal much variation among quadrats within the acidified and undisturbed groups. Mean growth rates were significantly different in 1981 and 1982 (3 and 4 growing seasons after the spill), but no difference was noted after that time, suggesting the maximum duration of effects was four growing seasons.

The variation among quadrats was probably partly attributable to differences in the ages of trees sampled. Older trees tend to grow much more slowly because of the larger proportion of non-photosynethetic tissue (i.e. branches

TABLE 4 Mean Growth Rates (and Standard Deviations) of Hawthorn (Crataegus Macrosperma) in Undisturbed and Acidified Quadrats for the Last Five Years.

	Undisturbed Quadrats (mm/y)											Acidified Quadrats (mm/y)							
Years Ago (Year)	J	P	Q	R	T	U	V	W	X	Y	All Undis-turbed	B	C	E	H	M	N	O	All Acidi-fied
1 (1985)	0.72	0.39	0.68	0.36	0.06	0.29	0.25	0.49	0.60	0.42	0.42	1.26	0.84	0.63	0.53	0.64	0.28	0.52	0.60
	(0.37)	(0.35)	(0.49)	(0.11)	(0.05)	(0.24)	(0.17)	(0.25)	(0.58)	(0.32)	(0.37)	(0.32)	(0.17)	(0.34)	(0.54)	(0.36)	(0.28)	(0.35)	(0.44)
2 (1984)	0.76	0.78	1.17	0.40	0.09	0.38	0.27	0.46	0.77	0.54	0.55	1.09	0.41	0.78	0.48	0.87	0.29	0.59	0.63
	(0.31)	(0.55)	(0.76)	(0.19)	(0.04)	(0.29)	(0.26)	(0.22)	(0.48)	(0.34)	(0.47)	(0.27)	(***)	(0.16)	(0.35)	(0.48)	(0.24)	(0.51)	(0.43)
3 (1983)	0.89	0.98	1.08	0.67	0.16	0.38	0.26	0.40	0.86	0.60	0.61	1.61	0.87	0.89	0.57	0.74	0.36	0.76	0.74
	(0.44)	(0.54)	(0.66)	(0.40)	(0.12)	(0.28)	(0.18)	(0.17)	(0.45)	(0.40)	(0.48)	(0.38)	(***)	(0.15)	(0.38)	(0.51)	(0.38)	(0.67)	(0.53)
4 (1982)	1.34	1.31	1.27	1.02	0.19	0.53	0.25	0.67	1.15	0.90	0.84*			1.34	0.70	0.67	0.33	0.74	0.75*
	(0.76)	(0.65)	(0.46)	(0.53)	(0.19)	(0.41)	(0.16)	(0.34)	(0.50)	(0.43)	(0.61)			(0.27)	(0.44)	(0.25)	(0.36)	(0.46)	(0.49)
5 (1981)	1.72	1.47	1.79	1.07	0.28	0.55	0.29	1.08	1.09	1.25	0.91*			1.78	0.81	0.90	0.35	0.92	0.76*
	(0.90)	(0.70)	(0.47)	(0.52)	(0.15)	(0.53)	(0.19)	(0.54)	(0.44)	(0.72)	(0.73)			(***)	(0.29)	(0.48)	(0.31)	(0.49)	(0.48)

* significantly different at the 0.05 confidence level.
** significantly different at the 0.01 confidence level.
*** standard deviation cannot be computed because N=1.

and boles) in their structure, which adds to respiration costs, and because of cellular senescence, which interferes with the efficient functioning of the tree. This decline in growth rate may mask acid-induced growth deficiencies when older surviving trees are compared to young trees growing on the acidified sites.

A means of eliminating this bias in the data would be to compare the growth rates of the first few years of growth of surviving trees to those of the trees recolonizing the acidified sites. Table 5 presents ring width data for the first 5 years growth of Hawthorn growing under acidified and non-acidified conditions. Variation among quadrats is somewhat reduced in this data set, indicating that age differences were a major source of variability in the data. Comparison of the means for acidified and non-acidified quadrats showed no significant differences in growth rates for 2, 3 and 5 year old Hawthorns. At age four the mean ring width for shrubs growing in undisturbed quadrats was significantly higher (at the .05 confidence interval) than the mean ring width for shrubs growing in acidified quadrats. No reason for this difference was apparent. At age one, mean ring width for the shrubs in the undisturbed quadrats was significantly higher than ring width growth for the shrubs in the acidified quadrats. This is consistent with the results of the previous analysis, as age one shrubs on acidified sites would have germinated in 1981, the third growing season after the spill.

A disadvantage of the above method of analysis is that is does not compensate for variations in growth caused by year-to-year variations in weather patterns. This particular bias can be overcome by comparing the growth rates of shrubs of the same age and species during the same time period. Unfortunately, this reduces the number of replicates, thereby counteracting some of the benefit gained. Data of this type are presented in Table 6. This data shows that there were no significant differences in the mean annual ring growth of shrubs on acidified or undisturbed quadrats over the past four growing seasons. However, in 1981, five growing seasons ago, or three growing seasons after the spill, the mean annual ring width for Hawthorn in undisturbed quadrats was found to be significantly higher than the mean annual

TABLE 5 Mean Growth Rates (and Standard Deviations) of Hawthorn (Crataegus macrosperma) in Undisturbed and Acidified Quadrats for the First Five Years of Shrub Growth.

	Undisturbed Quadrats (mm/y)													Acidified Quadrats (mm/y)					
Years of Age	J	N	O	P	Q	R	T	U	V	W	X	Y	All Undis-turbed	B	C	E	H	M	All Acidi-fied
1	2.12	1.21	1.20	1.51	1.81	1.47	1.66	1.75	0.48	1.86	1.04	1.59	1.45**	1.49	0.91	1.41	1.03	1.26	1.24**
	(0.56)	(0.32)	(0.49)	(0.42)	(0.43)	(0.34)	(0.32)	(0.32)	(0.16)	(0.57)	(0.47)	(0.54)	(0.61)	(0.44)	(0.06)	(0.27)	(0.31)	(0.35)	(0.38)
2	0.85	0.80	1.00	1.06	1.30	0.84	1.01	1.34	0.32	0.62	1.07	0.88	0.92	1.13	0.41	0.90	0.85	0.95	0.92
	(0.49)	(0.27)	(0.32)	(0.67)	(0.46)	(0.18)	(0.25)	(0.60)	(0.14)	(0.26)	(0.45)	(0.37)	(0.52)	(0.26)	(***)	(0.16)	(0.28)	(0.43)	(0.31)
3	0.82	0.78	0.67	0.84	1.09	0.47	0.69	1.14	0.30	0.45	0.85	0.59	0.72	1.28		0.78	0.59	0.70	0.75
	(0.48)	(0.36)	(0.36)	(0.59)	(0.67)	(0.29)	(0.17)	(0.65)	(0.14)	(0.17)	(0.40)	(0.26)	(0.49)	(0.36)		(0.16)	(0.33)	(0.21)	(0.34)
4	0.73	0.79	0.54	0.69	0.98	0.39	0.72	1.08	0.38	0.42	0.78	0.59	0.68*			0.61	0.43	0.69	0.61*
	(0.37)	(0.36)	(0.36)	(0.57)	(0.72)	(0.21)	(0.20)	(0.59)	(0.27)	(0.22)	(0.49)	(0.21)	(0.47)			(0.31)	(0.32)	(0.16)	(0.31)
5 (1981)	0.74	0.61	0.81	0.54	0.77	0.42	0.74	0.83	0.33	0.48	0.62	0.44	0.59			1.11	0.45	0.49	0.61
	(0.31)	(0.43)	(0.61)	(0.31)	(0.55)	(0.23)	(0.21)	(0.44)	(0.14)	(0.20)	(0.63)	(0.32)	(0.39)			(***)	(0.37)	(0.36)	(0.46)

* significantly different at the 0.05 confidence level.
** significantly different at the 0.01 confidence level.
*** standard deviation cannot be computed because N-1.

TABLE 6 Mean Growth Rates (and Standard Deviations) of Four to Seven Year Old Hawthorn (Crataegus macrosperma) in Undisturbed and Acidified Quadrats During the Last Five Years.

	Undisturbed Quadrats (mm/y)							Acidified Quadrats (mm/y)			
Years Ago (Year)	J	P	Q	W	X	Y	All Undis-turbed	E	H	M	All Acidi-fied
1 (1985)	0.72	0.33	0.68	0.49	0.60	0.40	0.55	0.63	0.64	0.67	0.59
	(0.37)	(0.32)	(0.49)	(0.25)	(0.58)	(0.34)	(0.42)	(0.34)	(0.63)	(0.52)	(0.45)
2 (1984)	0.76	0.79	1.17	0.46	0.78	0.62	0.76	0.77	0.48	0.87	0.66
	(0.31)	(0.59)	(0.76)	(0.22)	(0.48)	(0.26)	(0.51)	(0.16)	(0.35)	(0.63)	(0.37)
3 (1983)	0.89	1.09	1.08	0.40	0.86	0.63	0.81	0.89	0.57	0.43	0.67
	(0.44)	(0.53)	(0.66)	(0.17)	(0.45)	(0.31)	(0.50)	(0.15)	(0.37)	(0.37)	(0.34)
4 (1982)	1.34	1.53	1.27	0.67	1.15	1.05	1.14	1.34	0.69	0.83	0.97
	(0.76)	(0.44)	(0.46)	(0.34)	(0.51)	(0.35)	(0.55)	(0.27)	(0.44)	(0.08)	(0.45)
5 (1981)	1.72	1.82	1.74	1.08	1.09	1.77	1.48**	1.78	0.81	0.91	0.90**
	(0.90)	(0.47)	(0.47)	(0.54)	(0.44)	(0.32)	(0.62)	(***)	(0.29)	(0.29)	(0.37)

* significantly different at the 0.05 confidence level.
** significantly different at the 0.01 confidence level.
*** standard deviation cannot be computed because N=1.

ring width for shrubs on acidified quadrats. This is consistent with both of the previous analyses. It would therefore appear that the acid spill produced on acute stress on the plant community which quickly abated.

From the above, it can be concluded that the duration of measurable effects of the acid spill on shrub growth lasted from three to four growing seasons. It should also be noted that growth rate differences measured three growing seasons after the spill, although statistically significant, were not dramatically large.

5.3 IMPACTS OF SPILL ON PLANT SPECIES COMPOSITION

5.3.1 Distribution of Plant Communities

As noted earlier, certain species associations appear to be associated with different disturbance regimes. The Goldenrod and Bentgrass-Goldenrod communities (Figure 6; quadrats A, B, C, D) were found in the fill zone which was chemically disturbed during the acid spill and physically disturbed when the wreckage was removed and fill was spread over the site. The ground vegetation was the dominant vegetation component in these quadrats, as illustrated by their low total shrub basal area and total stem density. The mean ages of the 10 largest shrubs in quadrats A, B, and C were 3.0, 2.8 and 2.1 years, respectively (Figure 7). Shrubs have yet to colonize quadrat D. The slow rate of shrub colonization of these quadrats was probably attributable to the sandy fill used to cover the site of the spill. The high permeability of this fill combined with its low organic matter content would result in seasonal dryness of the site.

The chemically disturbed zone (identified by the presence of standing dead trees and shrubs) tended to be dominated by the Hardhack-Alder community (Figure 6; quadrats L, M, N and S). Successionally, this community appeared to be more advanced than the Bentgrass-Goldenrod or Goldenrod communities. As mentioned earlier, the total basal area and mean ages of the shrubs of these quadrats tended to be higher than those of the Bentgrass-Goldenrod and Golden-

rod communities, suggesting that they recovered from the disturbance more quickly. The preservation of the organic layer of the soil, attributable to the lack of physical disturbance in this area could contribute to the rapid recovery of the vegetation in this area in four possible ways.

1) Organic matter would provide additional ion exchange sites making this zone more nutrient rich, thereby, allowing more rapid vegetation growth.
2) The decomposition of organic matter would release nutrients which would become available to newly-established plants.

3) Seeds stored in the organic layer (provided they survived the acidification) would provide a ready source of propagules to recolonize the site.

4) Higher levels of organic matter would allow for the retention of more water which would reduce the incidence of seasonal drought.

5.3.2 Distribution of Shrub Species

The distribution of individual shrub species appears to have been influenced to a certain degree by the acid spill. Gray Birch (Betula populifolia), Downy Alder (Alnus crispa), Beaked Willow (Salix Bebbiana) and Pin Cherry (Prunus pensylvanica) were distributed only within the fill and chemically disturbed zones (Figure 12 to 15). The occurrence of these species in these disturbed areas is probably attributable to their seed dispersal strategies. Downy Alder, Beaked Willow and Gray Birch utilize the fugitive seed strategy in which a large number of light seeds capable of long-distance wind transport are produced by mature trees. A disadvantage of light seeds is the limited amount of food which can be stored in them to assist the initial growth of the seedling. In an area with an established cover of vegetation, few seedlings survive because they exhaust stored food before they can grow into an opening in the vegetation canopy. Immediately after the acid spill, the shrub and ground layers of vegetation in the affected areas would have been eliminated allowing large numbers of Downy Alder, Beaked Willow and Gray Birch seeds to germinate and survive. Downy Alder would have had an additional competitive advantage in that it is a nitrogen fixing plant and would have been able to supplement the meager supplies of nitrogen on the site.

DISTRIBUTION OF BASAL AREA OF GRAY BIRCH (*Betula populifolia*)

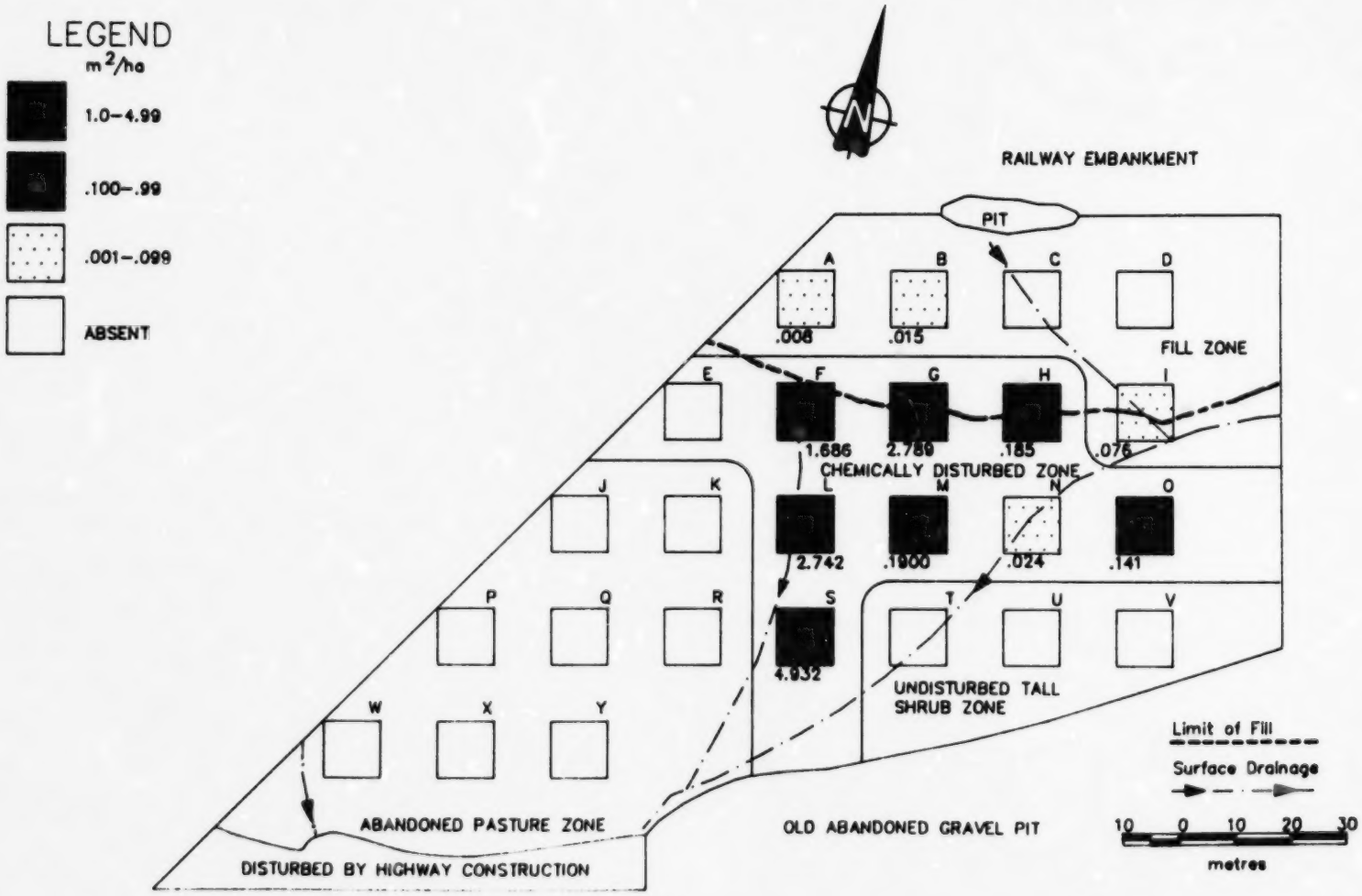


Figure 12

DISTRIBUTION OF BASAL AREA OF DOWN ALDER *(Alnus crispa)*

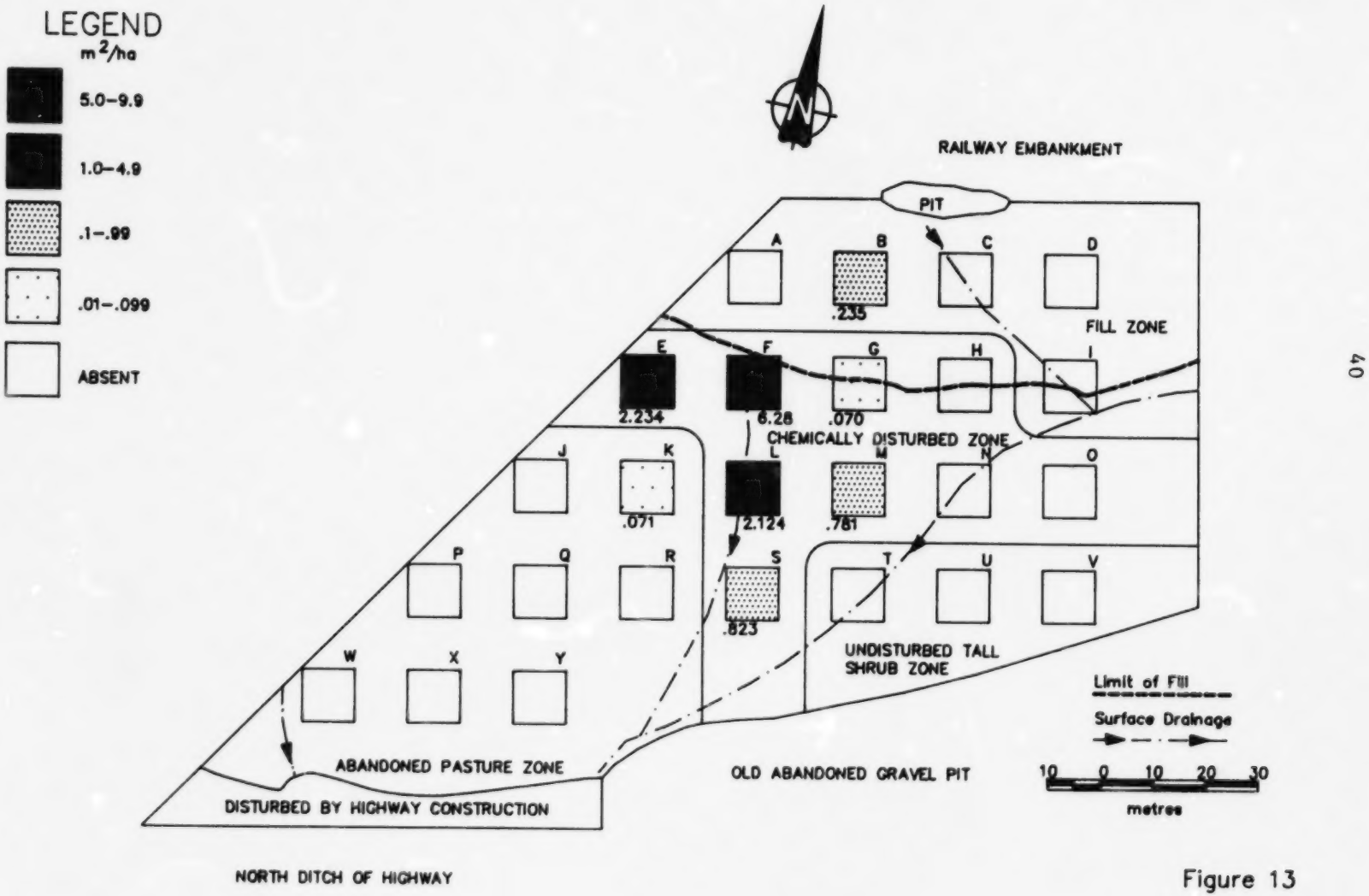


Figure 13

DISTRIBUTION OF BASAL AREA OF BEAKED WILLOW *(Salix bebbiana)*

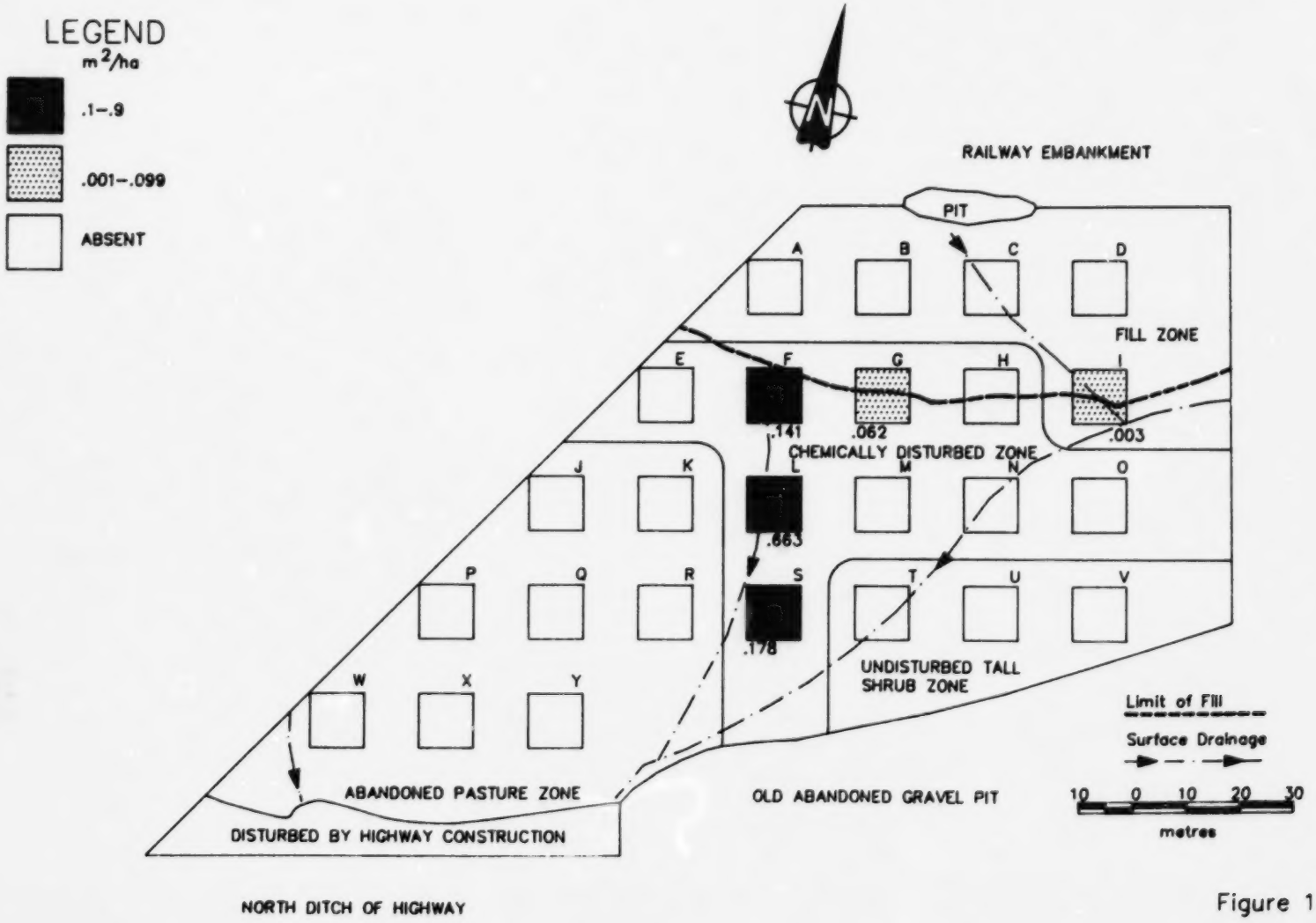


Figure 14

DISTRIBUTION OF BASAL AREA OF PIN CHERRY *(Prunus pensylvanica)*

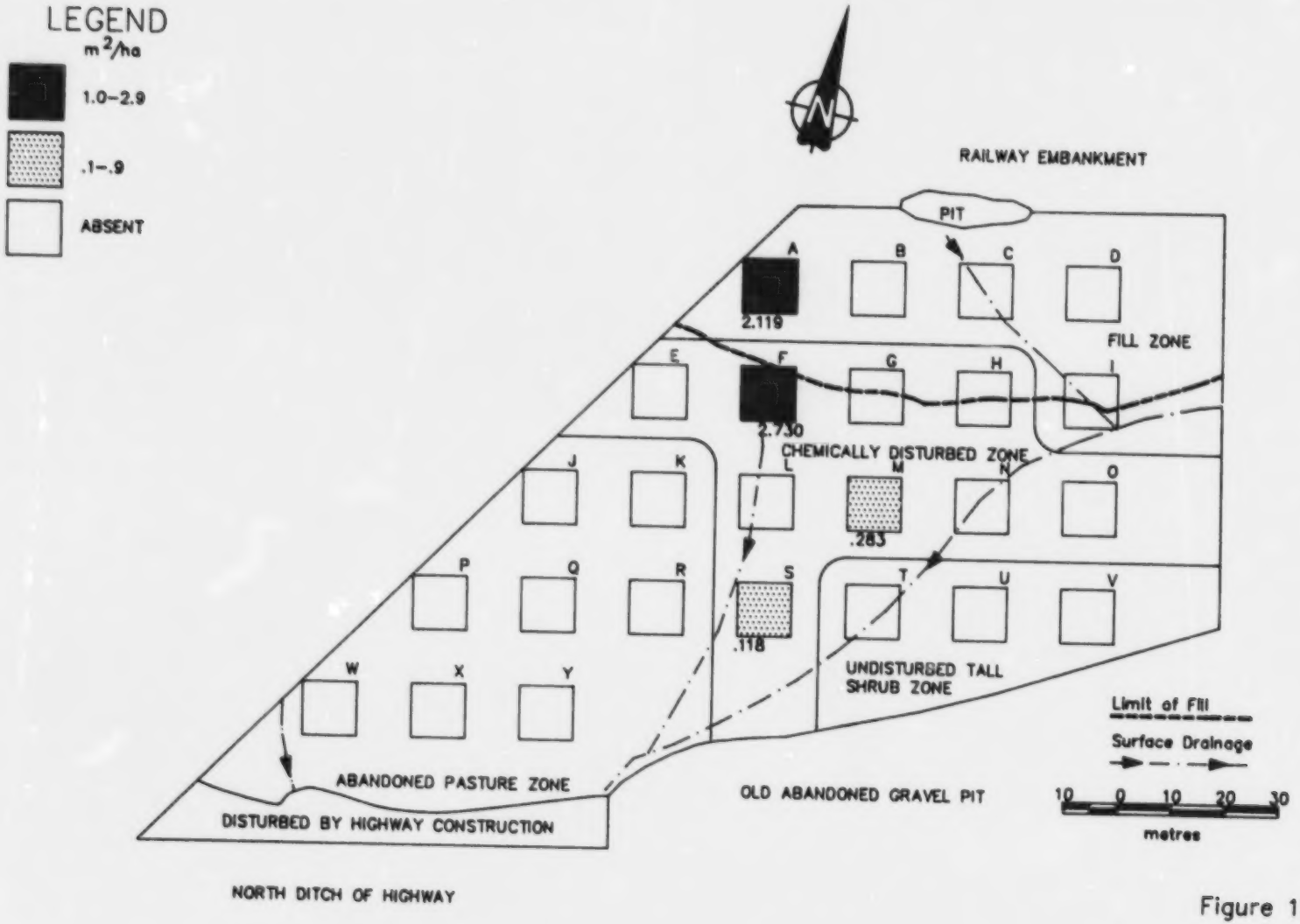


Figure 15

Pin Cherry utilizes the buried seed strategy in which seeds are accumulated and stored in the soil for up to 50 years until environmental changes associated with disturbance cause the seeds to germinate. The seeds of this species are very resistant to environmental extremes and many of them may have survived the acid spill.

Hawthorn, the dominant species of much of the abandoned pasture in the study area, utilizes neither of the above-described strategies and would not be able to match the rate of recolonization exhibited by the previous four species. Its distribution is patchy within the area receiving the major impact of the acid spill (Figure 16). This is even more readily apparent when the ratio of its basal area to that of other shrub species in the same quadrat is compared (Figure 17).

5.3.3 Ground Vegetation

The impact of the various disturbances regimes on the ground vegetation was determined by analyzing the distribution of each of the species that comprise this layer. Each species was assigned a letter code according to the environmental zone in which it was found to occur (A = abandoned pasture; B = undisturbed tall shrub; C = chemically disturbed; D = fill). Combinations of letters were assigned to species which were found in more than one zone. The results of this investigation are presented in Table 7. These data reveal that 34 out of 70 ground vegetation species occurred only within a particular environmental zone. Ten species occurred exclusively within the abandoned pasture zone. These species are characteristic of the early stages of old field succession on naturally acidic sites. Three species were found only in the undisturbed tall shrub zone and are typically found in open woodlands. Ten species were noted only in the fill zone. These species are generally found in areas with exposed mineral soil and are typical of roadsides and railway embankments. The railway roadbed bordering this zone was probably the source of seeds of these species. The chemically disturbed zone contained 11 species which occurred nowhere else in the study area. These species are characteristic of the early stage of forest succession rather than old field

DISTRIBUTION OF BASAL AREA OF HAWTHORN *(Crataegus macrosperma)*

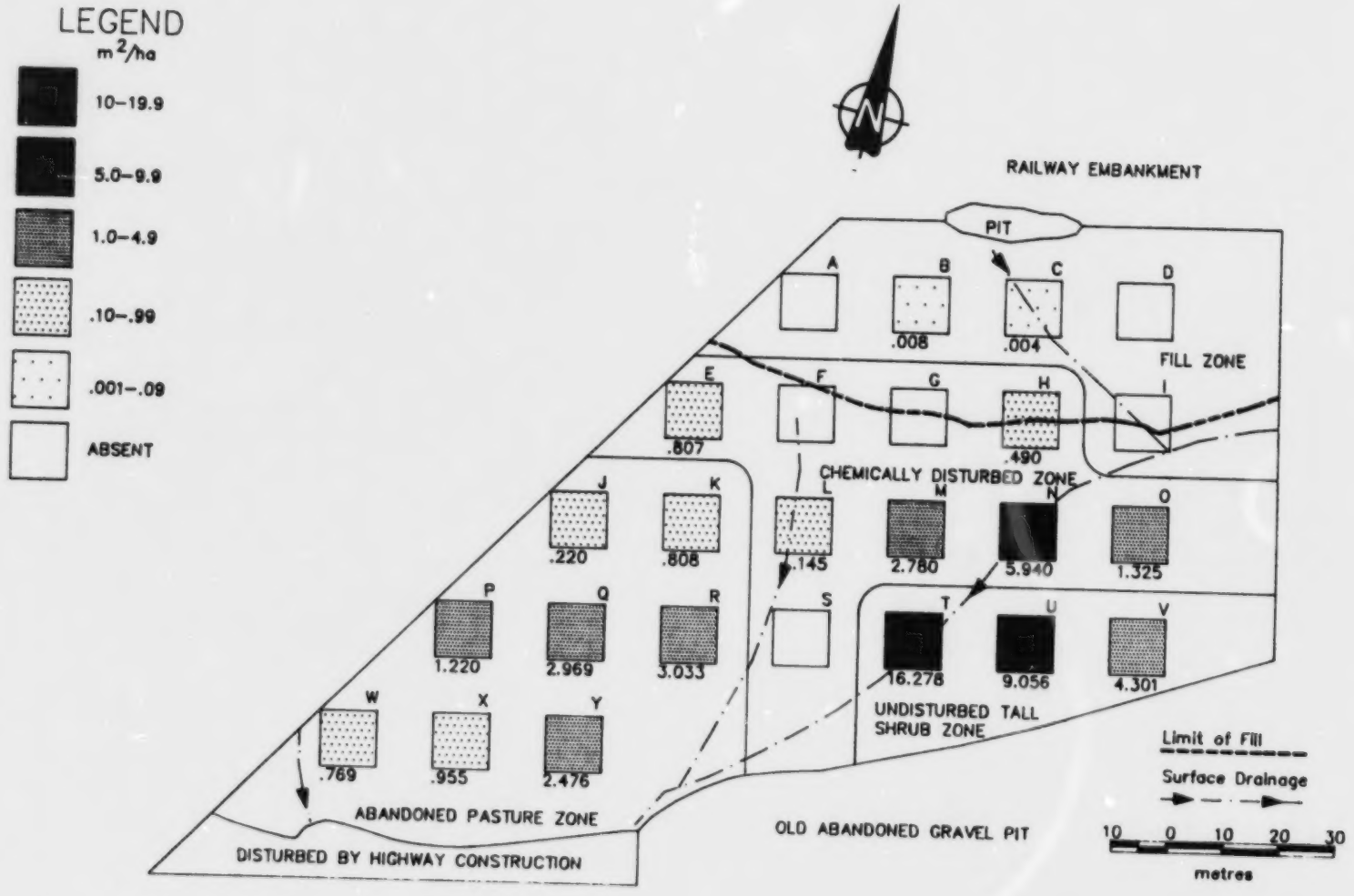


Figure 16

RATIO OF BASAL AREA OF HAWTHORN *(Crataegus macrosperma)* TO BASAL AREA OF ALL SHRUBS.

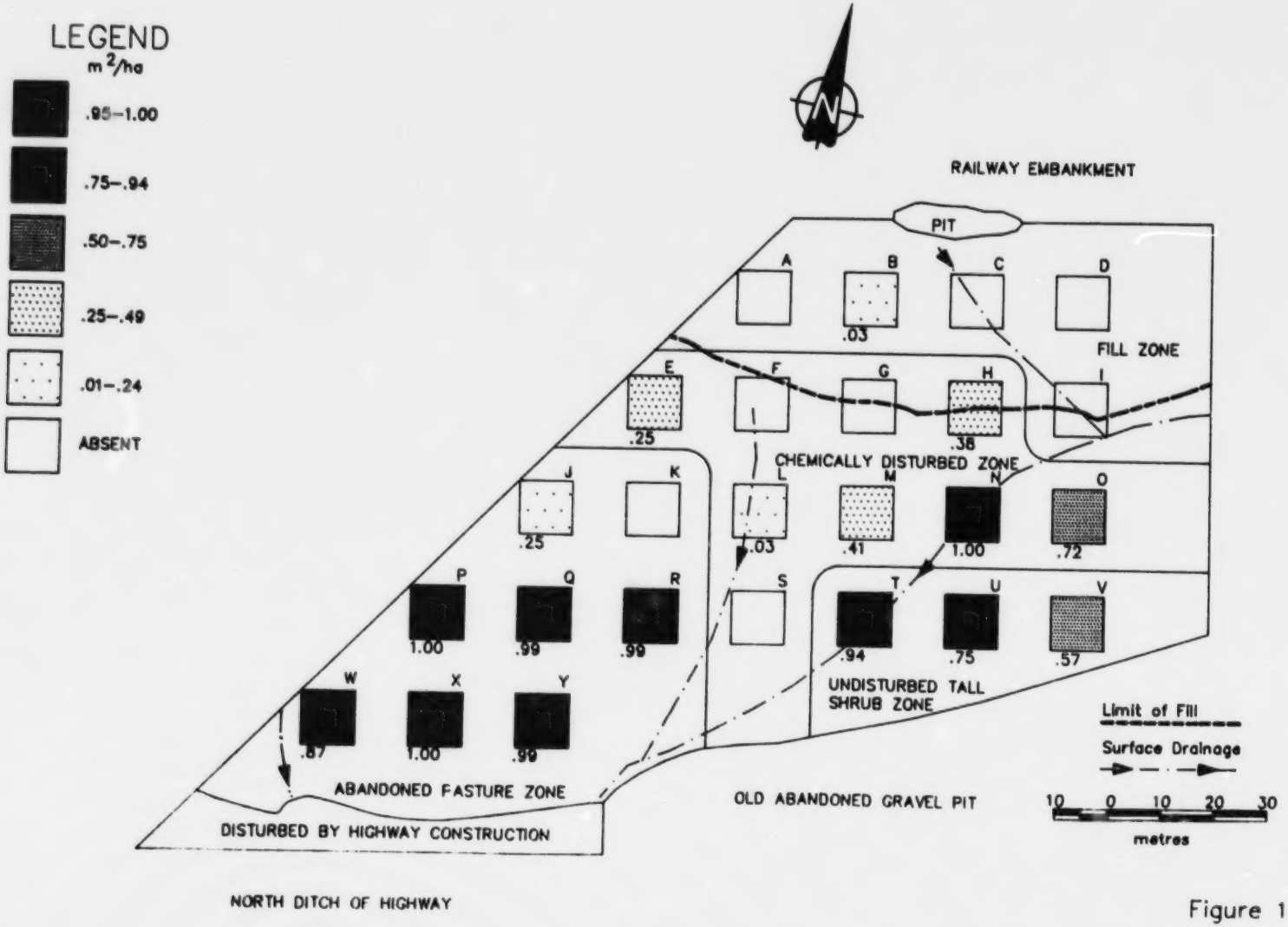


Figure 17

TABLE 7 Distribution of Species of the Ground Vegetation in the Four Environmental Zones of the Detailed Study Area

Scientific Name	Common Name	Envir.Zone	Scientific Name	Common Name	Envir.Zone
Achillea lanulosa	Yarrow	A	Leontondon autumnalis	Fall Dandelion	C*
Agropyron repens	Quack Grass	C	Oenothera sp.	Evening Primrose	C
Agrostis alba	Redtop	ABCD	Panicum lanuginosum	Panic Grass	B*
Agrostis tenuis	Bentgrass	ABCD	Panicum sp.	Panic Grass	ABCD
Anaphalis margaratacese	Pearly Everlasting	D	Phleum pratensis	Timothy	C
Antennaria neodioica	Everlasting	A	Plantago lanceolata	English Plantain	A
Aralia hispida	Bristly Aralia	D	Poa compressa	Canada Bluegrass	C
Aronia prunifolia	Chokeberry	A	Poa palustris	Meadow Grass	C
Aster cordifolius	Heart-leaved Aster	BD	Poa pratensis	Kentucky Bluegrass	CD
Aster lateriflorus	Calico Aster	BD	Potentilla canadensis	Dwarf Cinquefoil	ACD
Aster Umbellatus	Tall White Aster	BCD	Potentilla recta	Rough-fruited Cinquefoil	A
Carex conoidea	Sedge	A	Prenanthes trifoliata	Lion's Paw	D*
Carex debilis	Sedge	CD	Rosa carolina	Pasture Rose	AD
Carex Hougtonii	Sedge	C*	Rubus allegheniensis	Blackberry	D
Carex projecta	Sedge	C	Rubus recurvicaulis	Blackberry	ACD
Carex scoparia	Sedge	CD	Rubus strigosus	Wild Raspberry	BCD
Carex spp.	Sedge	ABCD	Rubus vermontanus	Blackberry	D
Chrysanthemum leucanthemum	Ox-eye Daisy	AC	Rumex acetosella	Sheep Sorrel	BCD
Circium arvense	Canada Thistle	AC	Scirpus cyperinus	Bulrush	D
Comptonia peregrina	Sweetfern	C	Sisyrinchium montanum	Blue-eyed Grass	A
Danthonia spicata	Poverty Grass	AD	Solidago bicolor	White Goldenrod	AD
Dennstaedtia punctilobula	Hay-scented Fern	D	Solidaga canadensis	Canada Goldenrod	BCD
Dryopteris spinulosa	Wood Fern	D*	Solidago graminifolia	Narrow-leaved Goldenrod	BCD
Erigeron annuus	Daisy Fleabane	A	Solidago rugosa	Rough Goldenrod	ABCD
Festuca capillata	Hair Fescue	AD	Spartina pectinata	Broadleaf	C
Festuca rubra	Red Fescue	A	Spiraea latifolia	Hardhack	ABCD
Fragaria virginiana	Wild Strawberry	ABCD	Spiraea tomentosa	Steeplebush	D*
Geum macrophyllum	Large-leaved Avens	B	Vaccinium angustifolium	Blueberry	ABCD
Hieracium aurantiacum	Orange Hawkweed	BCD	Vaccinium myrtilloides	Canada Blueberry	A
Hieracium Pilosella	Mouse-ear Hawkweed	ACD	Veronica officinalis	Common Speedwell	BCD
Hypericum perfoliatum	Common St.John's Wart	C	Vicia cracca	Tufted Vetch	ACD
Impatiens sp.	Touch-me-not	D*	Viola incognita	White Violet	B
Juncus effusus	Soft Rush	CD	Viola septentrionalis	Northern Blue Violet	D
Juncus tenuis	Rush	ACD		Cushion Moss	BD
Lactuca canadensis	Wild Lettuce	BD		Feather Moss	BD

succession. Succession in this area was set back to an earlier stage and shifted in a different direction by the chemical disturbance. This is confirmed by the changes in shrub species composition which were discussed earlier. These specialist species accounted for only a small proportion (9.3 average %) of the total ground vegetation cover for each quadrat, regardless of the zone in which they were found.

Fifteen species were found in two out of four zones. This group was somewhat less specialized in their habitat preferences. From experience in other areas it is known these species combinations are quite common outside of the study area. The five species which occurred in the abandoned pasture and chemically disturbed zones (AD) as well as the two species found in the abandoned pasture and fill zones (AC) are typical of abandoned pasture over much of Nova Scotia. The four species found in the fill and the chemically disturbed zones (CD) are commonly found in areas with exposed mineral soil while the five species occurring in the undisturbed tall shrub and chemically disturbed zones (BD) are typically found on clear-cuts, burnt areas or open forests. These somewhat less specialized species accounted for an average of only 9.9% of the total ground vegetation coverage.

Twelve species occurred in three out of four zones. These species are common in a wide variety of early successional plant communities throughout Nova Scotia. They accounted for an average of 25.7% of the total ground vegetation coverage.

Eight species were found throughout the study area. These species are very common throughout the province, occurring in many plant communities, although they are usually restricted to early to mid-successional stages. These species represented only 11.4% of the total number of ground vegetation species in the study area, yet they constituted an average of 55.1% of the total ground vegetation cover. These data reveal that vigorous early successional species with apparently few specific habitat requirements are most successful in the study area. In addition, an average of 80.8% of the total ground vegetation cover for the study area was composed of species capable of

growing on 3 or 4 of the environmental zones (including both disturbed zones). In summary, the plants that predominate on the acid-disturbed site are those that would be expected on any disturbed site. This would indicate that the acid spill did not create any long term toxicity effects on plants. The above conclusion is confirmed by the absence of significant invasion by highly acid-tolerant or salt-tolerant plants. Of the 83 species of vascular plants found in the study area, only one highly salt-tolerant species was found. This was the grass, Spartina pectinata, a species that often inhabits ditches along roads subjected to salting. This species was encountered in quadrats H and I and several large patches were noted in the vicinity of quadrat D. These locations coincide with the predicted surface flow path of highly saline water draining the sodium sulphate deposits (product of neutralizing sulphuric acid with sodium hydroxide) found in the pit into which much of the acid flowed.

5.4 MULTIVARIATE ANALYSIS OF VEGETATION DATA

The results of the multivariate cluster analysis for the shrub and ground vegetation are summarized in Figures 18 and 19. It can be seen that the clustering of the data is not as distinct as that obtained from partitioning the environment on the basis of physical evidence of past spill-related damage (refer back to Figure 8).

The abandoned pasture zone shows up very clearly as a distinct zone in the multivariate analysis of shrub vegetation, presumably because of its recent and relatively consistent invasion by Hawthorn, which appears to be simply a stage in old field succession rather than an effect of the acid spill. The multivariate analysis of ground vegetation demonstrates great variable in the abandoned pasture zone. This is consistent with our expectation for a fairly transitory stage in natural succession.

The fill zone, which shows up clearly as a distinct zone from simple examination in the field, also shows up clearly in both the shrub and ground vegetation data sets, although each data set provides a slightly different interpretation of the extent of the zone.

RESULTS OF CLUSTER ANALYSIS FOR SHRUBS.

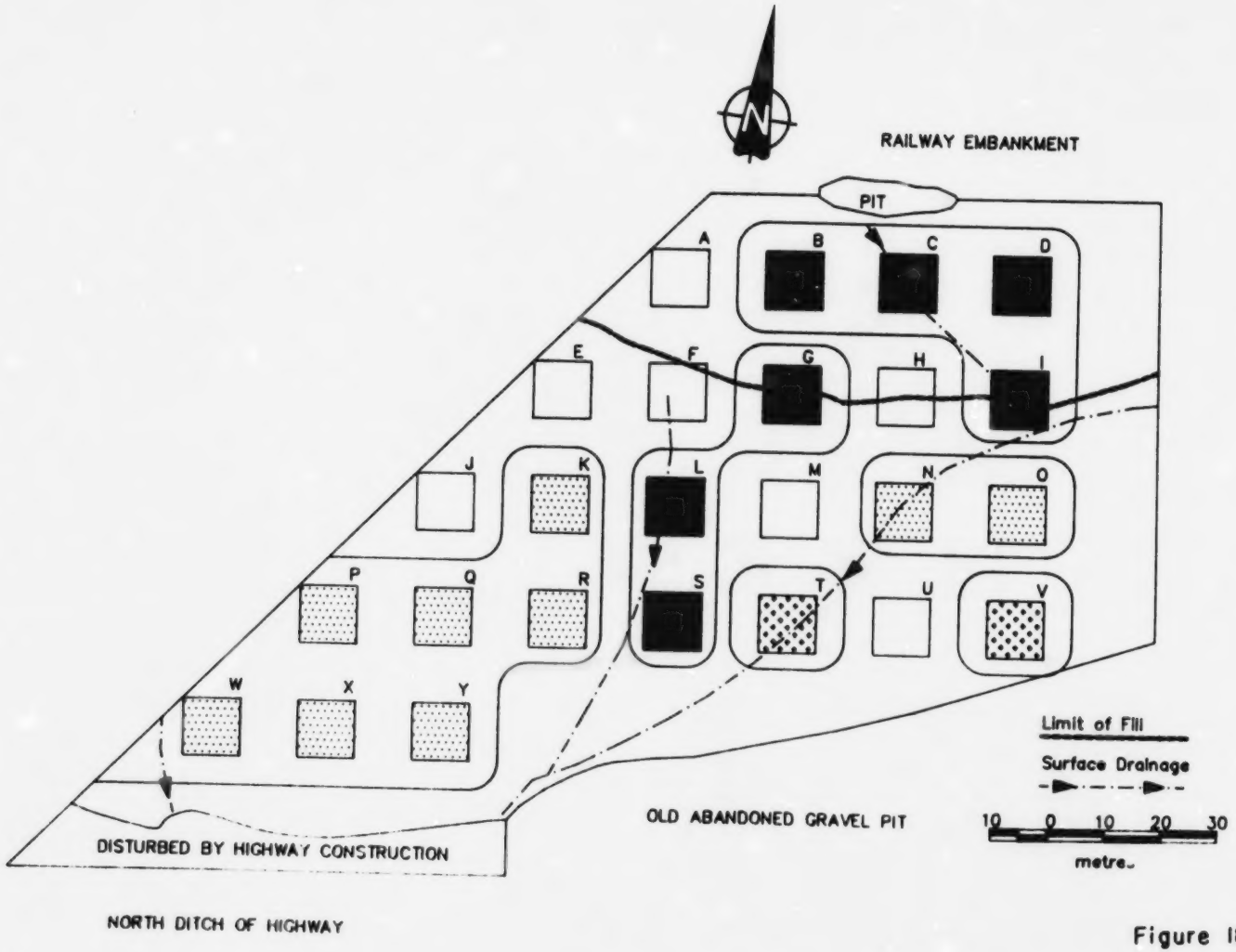


Figure 18

RESULTS CLUSTER ANALYSIS FOR GROUND VEGETATION.

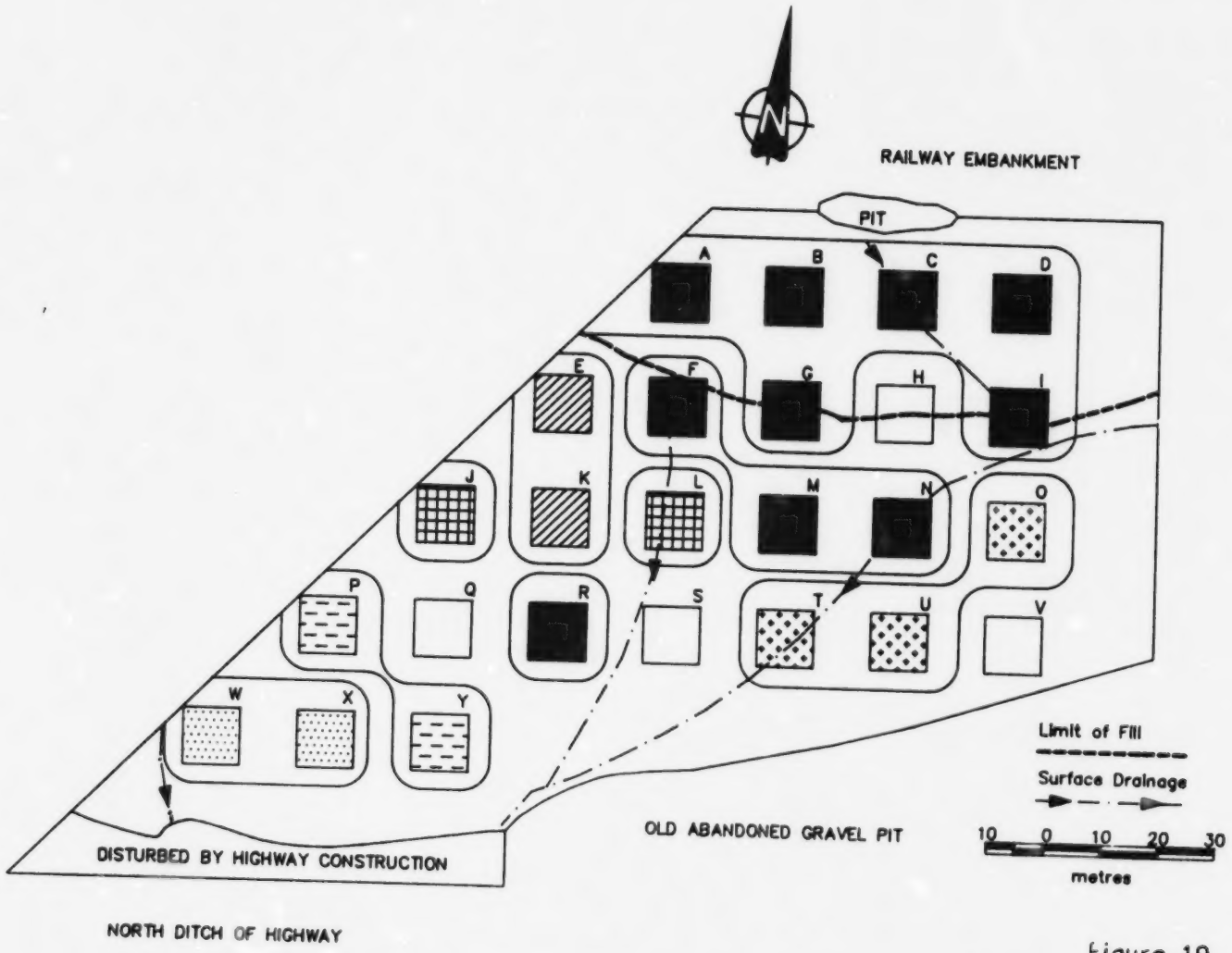


Figure 19

In the zone where the presence of dead shrubs indicated a past effect of the spill, the results of cluster analysis for both the shrub and ground layer do not show a clear-cut zone of impact. Only quadrats G, L and S show a pattern in the shrub layer that is distinctive to the area previously affected by the spill (chemically disturbed zone). In all other quadrats in the chemically disturbed zone, there is no consistent pattern in the shrub layer. In the ground vegetation there is no clustering of data in the chemically disturbed zone that is unique to that zone. The relative lack of a distinct pattern of vegetation in previously disturbed areas, suggests that the effects have been subtle and variable, except for those cases where terrain disturbance accompanied the spill.

5.5 SOILS OF THE STUDY AREA

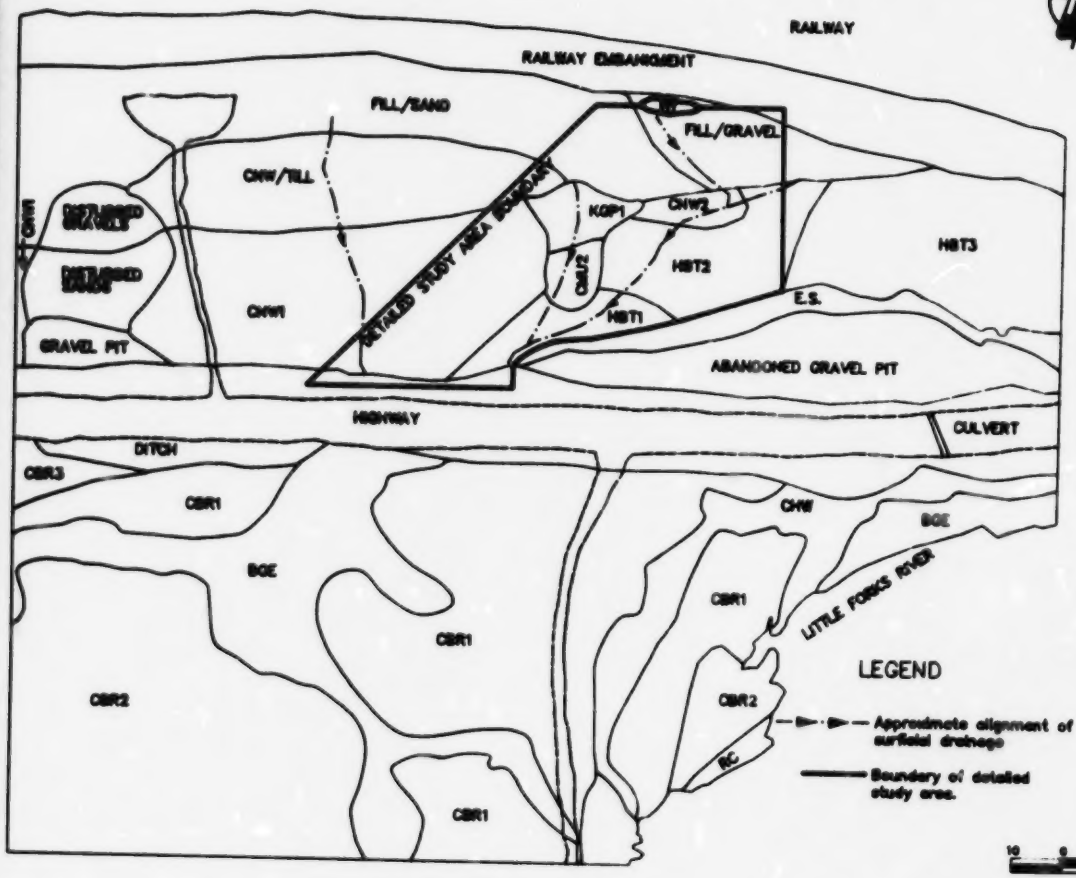
A map of the soils of the study area is provided on Figure 20. South of the highway Cumberland, Bridgeport and Chaswood soils have developed on sands and gravels of relatively recent fluvial origin. Free draining Cumberland soils (orthic regosols) predominate, although the proportion of the area occupied by imperfectly drained Bridgeville soils is significant. Poorly drained Chaswood soils (rego gleysols) are found on intermittently flooded former channels of the Little Forks River.

North of the highway, glaciofluvial Cornwallis and Hebert soils predominate. The former are sandy in texture and the latter gravelly. Both are well drained. Small areas of Kingsport and Comeau soils, the imperfectly drained equivalents of Cornwallis and Hebert soils, respectively, are found in the centre of the area affected by the spill.

The complexity of soil conditions in the area directly affected by the spill is illustrated in Figure 21. Six individual soil types and two types of fill, exhibiting a variety of textural and drainage characteristics found within an area of 0.3 hectares.

SOILS MAP

(TOTAL STUDY AREA)



LEGEND

SOIL NAME	MAP SYMBOL	SOIL DESCRIPTION
HEBERT	HBT1	Glaciofluvial gravelly soils with gravels right to the surface. Well drained on south facing 5–9% slopes.
	HBT2	Glaciofluvial gravelly soils with sandy surfaces to 50cm. Well drained on south facing 2–5% slopes.
	HBT3	HBT 1 soils on 2–5% south facing slopes
COMEAU	CMU2	Imperfectly drained HBT2 soils on south facing 5–9% slopes.
CORNWALLIS	CNW1	Glaciofluvial sands (non–gravelly). Well drained on south facing 5–15% slopes.
	CNW2	CNW1 soils on south facing 2–5% slopes.
	CNW/TILL	CNW1 soils over glacial till material greater than 50 cm in depth. Well drained on south facing 5–9% slopes.
KINGSPORT	KGP1	Imperfectly drained CNW1 soils.
CUMBERLAND	CBR1	Fluvial soils,predominately sands (non–gravelly). Well drained on level to south facing 0.5–2% slopes.
	CBR2	Gravelly CBR1 soils.
	CBR3	CBR1 soils on upper terraces of the Little Forks River
BRIDGEVILLE	BGE	Imperfectly drained CBR1 and CBR2 soils.
CHASWOOD	CHW	Poorly drained CBR2 soils associated with periodically inundated channels of the Little Forks River.
FILL	FILL/GRAVEL	Disturbed sites with 50–75cm of bulldozed fill over HBT gravels on south facing 5–9% slopes.
	FILL/SAND	Disturbed sites with 50–75cm of bulldozed fill over CNW sands on south facing 2–5% slopes.
E.S.		Escarpment
R.C.		River channel

Figure 20

SOIL MAP OF DETAILED STUDY AREA.

LEGEND

SOIL NAME	MAP SYMBOL	SOIL DESCRIPTION
HEBERT	HBT1	Glaciofluvial gravelly soils with gravels right to the surface. Well drained on south facing 5–9% slopes.
	HBT2	Glaciofluvial gravelly soils with sandy surfaces to 50cm. Well drained on south facing 2–5% slopes.
	HBT3	HBT 1 soils on 2–5% south facing slopes
COMEAU	CMU2	Imperfectly drained HBT2 soils on south facing 5–9% slopes.
CORNWALLIS	CNW1	Glaciofluvial sands (non–gravelly). Well drained on south facing 5–15% slopes.
	CNW2	CNW1 soils on south facing 2–5% slopes.
	CNW/TILL	CNW1 soils over glacial till material greater than 50 cm in depth. Well drained on south facing 5–9% slopes.
KINGSPORT	KSP1	Imperfectly drained CNW1 soils.
CUMBERLAND	CBR1	Fluvial soils,predominantly sands (non–gravelly). Well drained on level to south facing 0.5–2% slopes.
	CBR2	Gravelly CBR1 soils.
	CBR3	CBR1 soils on upper terraces of the Little Forks River
BRIDGEVILLE	BGE	Imperfectly drained CBR1 and CBR2 soils.
CHASWOOD	CHW	Poorly drained CBR2 soils associated with periodically inundated channels of the Little Forks River.
FILL	FILL/GRAVEL	Disturbed sites with 50–75cm of bulldozed fill over HBT gravels on south facing 5–9% slopes.
	FILL/SAND	Disturbed sites with 50–75cm of bulldozed fill over CNW sands on south facing 2–5% slopes.
E.S.		Escarpment
R.C.		River channel

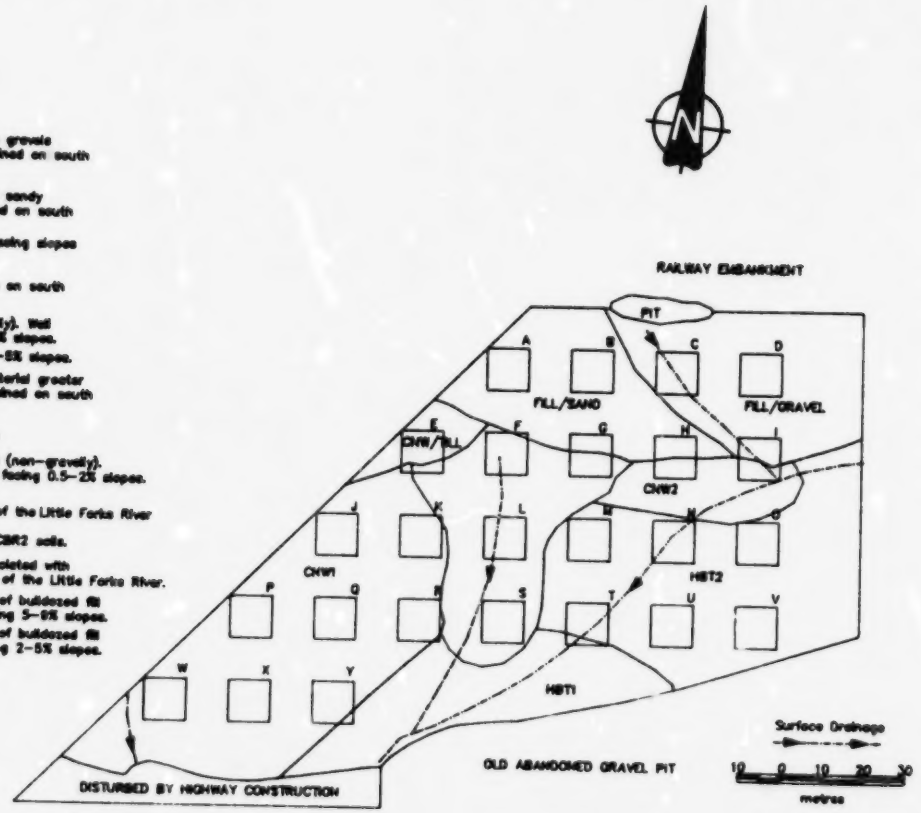


Figure 21

5.6 SOIL CHEMISTRY

Soil chemistry data collected from soil pits in the centre of each of the 25 quadrats in the detailed study area are summarized in Table 8. Soil pH measurements taken at locations throughout the overall study area (as per Figure 5) are provided in Table 9. A discussion of the significance of this data is provided in the subsections that follow:

5.6.1 Soil pH

A map of the soil pH contours of the overall study area is provided in Figure 22. Background pH levels are in the 4.6 to 5.0 range (very strongly acid), as would be expected in this part of Nova Scotia.

Lower soil pH values (4.0 - 4.5; extremely acid) appear to be associated with wetter areas, both on the slopes of the glaciofluvial terrace north of the highway and on the floodplain south of the highway. This may be a manifestation of natural variation in soil pH and may not have any relation to the past acid spill. It could, for example, be the result of locally high rates of soil leaching in these areas.

Soil pH values appreciably higher than the general background levels occur on parts of the floodplain south of the highway, in the vicinity of the ruins of a cellar north of the highway, and along the ditches on both sides of the highway. The first two instances may be related to past agricultural practices on the land, such as liming. Elevated pH in the ditches along the highways is probably the result of the use of road salt in winter. It would also conceivably be associated with the use of crushed limestone as a road building material.

There appears to be a soil pH anomaly directly south (downslope) of the pit into which much of the sulphuric acid disappeared during the 1978 spill. In the area, several soil pH readings of less than 4.0 (3.9, 3.1, 3.4, 3.8, 3.9, 3.9, 3.8, 3.4 for Quadrats D, F, G, H, I, M, N and S respectively) were recorded.

TABLE 8 Soil Chemistry Data for the Detailed Study Area

Sample	pH	Titratable Acidity @ pH8* (meq/100g)	Exchangeable Aluminum (meq/100g)	Exchangeable Calcium (meq/100g)	Exchangeable Magnesium (meq/100g)	Exchangeable Potassium (meq/100g)	Exchangeable Sodium (meq/100g)	Exchangeable Sulphate (meq/100g)	Electrical Conductivity (µMho)	Exchangeable Bases (meq/100g)	Cation Exchange Capacity (meq/100g)	Percent Base Saturation**
A	4.1	18	.078	1.134	.169	.126	.050	.084	63	1.479	1.557	95
B	4.1	5.6	.143	.516	.041	.096	.028	.187	31	.681	.824	82
C	4.0	16.8	.025	.927	.298	.181	.053	.076	40	1.459	1.484	98.3
D	3.9	23.6	.015	.689	.148	.092	.426	.023	34	1.355	1.370	98.9
E	4.3	15.2	.089	.615	.109	.122	.036	.168	62	.882	.971	90.8
F	3.1	9.2	.008	.182	.036	.064	.072	.305	80	.354	.362	97.8
G	3.4	14.4	.008	.189	.043	.051	.050	.101	48	.333	.341	97.7
H	3.8	6.0	.065	.118	.022	.020	.042	.487	45	.202	.267	75.7
I	3.9	10.0	.080	.086	.003	.028	.078	.476	77	.195	.275	70.9
J	4.1	8.8	.069	.077	.011	.064	.026	.325	32	.178	.247	72.1
K	4.9	13.6	.026	.354	.154	.077	.290	.017	26	.875	.901	97.1
L	5.0	9.4	.001	.524	.073	.092	2.251	.216	210	2.940	2.941	100
M	3.9	19.2	.211	.068	.004	.085	.041	.609	63	.198	.409	48.4
N	3.8	20.8	.101	.042	.002	.018	.024	.630	45	.086	.187	46.0
O	4.5	16.8	.086	.356	.048	.046	.030	.059	100	.480	.566	84.8
P	4.8	12.4	.094	.203	.029	.056	.022	.082	10	.310	.404	76.7
Q	4.8	12.0	.061	.836	.096	.103	.040	.029	11	1.075	1.136	94.6
R	5.2	10.4	.049	.378	.044	.030	.036	.065	11	.488	.537	76.7
S	3.4	10.4	.007	.149	.052	.038	.026	.006	23	.265	.272	97.4
T	4.2	15.6	.108	.061	.007	.045	.017	.059	19	.130	.238	54.6
U	4.6	15.2	.118	.197	.034	.070	.018	.027	17	.949	1.067	88.9
V	4.7	12.0	.066	.175	.044	.057	.018	.031	12	.294	.360	81.7
W	4.9	16.0	.048	.400	.054	.061	.024	.055	8.5	.539	.587	91.8
X	5.2	15.2	.019	1.063	.090	.042	.021	.004	7.5	1.216	1.235	98.5
Y	5.7	12.4	.038	1.361	.119	.064	.025	.006	13.5	1.569	1.607	97.6
Mean	4.3	13.6	.065	.428	.069	.069	.150	.165	44	.741	.806	84.6

* Barium Chloride - Triethanolamine ($BaCl_2$-TEA) Method

** % Base Saturation = $\frac{\text{Exchangeable Bases}}{\text{Exchangeable Bases + Exchangeable Aluminum}} \times 100$

TABLE 9 Soil pH Measurements from the Overall Study Area

Sample Location	pH of 'A' Horizon	pH of 'B' Horizon	pH of 'C' Horizon	Average pH
1	4.8	4.5	4.8	4.7
2	4.6	4.7	-	4.7
3	-	-	-	-
4	-	-	-	-
5	5.8	5.6	5.9	5.8
6	5.1	4.3	4.2	4.5
7	4.1	4.6	4.5	4.4
8	4.4	5.2	5.0	4.9
9	-	-	-	-
10	4.0	4.6	4.6	4.4
11	4.4	5.1	4.7	4.7
12	4.4	4.8	4.5	4.6
13	4.7(top 25cm)		4.7(lower 25cm)	4.7
14	-	-	-	-
15	4.4	5.3	4.4	4.7
16	4.7	4.7	4.7	4.7
17	-	-	-	-
18	-	-	-	-
19	-	-	-	-
20	4.8	4.5	4.8	4.7
21	4.5	4.8	4.7	4.7
22	4.6	5.2	5.3	5.0
23	4.2	5.0	4.4	4.5
24	5.4	5.2	5.1	5.2
25	4.1	4.5	3.4	4.0
26	5.3	4.9	4.1	4.8
27	4.5	6.1	6.0	5.5
28	6.4	6.9	6.9	6.7
29	4.9	4.8	4.6	4.8
30	4.3	5.1	5.3	4.9
31	5.2	6.4	6.8	6.1
32	-	-	-	-
33	6.0	4.8	4.5	5.1
34	6.1	5.7	5.0	5.6
35	5.3	4.4	4.6	4.8
36	4.8	4.3	4.0	4.4
37	4.0	4.5	4.5	4.3
38	4.6	4.3	4.2	4.4
39	4.2	4.1	4.2	4.2
40	4.5	5.2	4.9	4.9

pH IN $CaCl_2$
(TOTAL STUDY AREA)

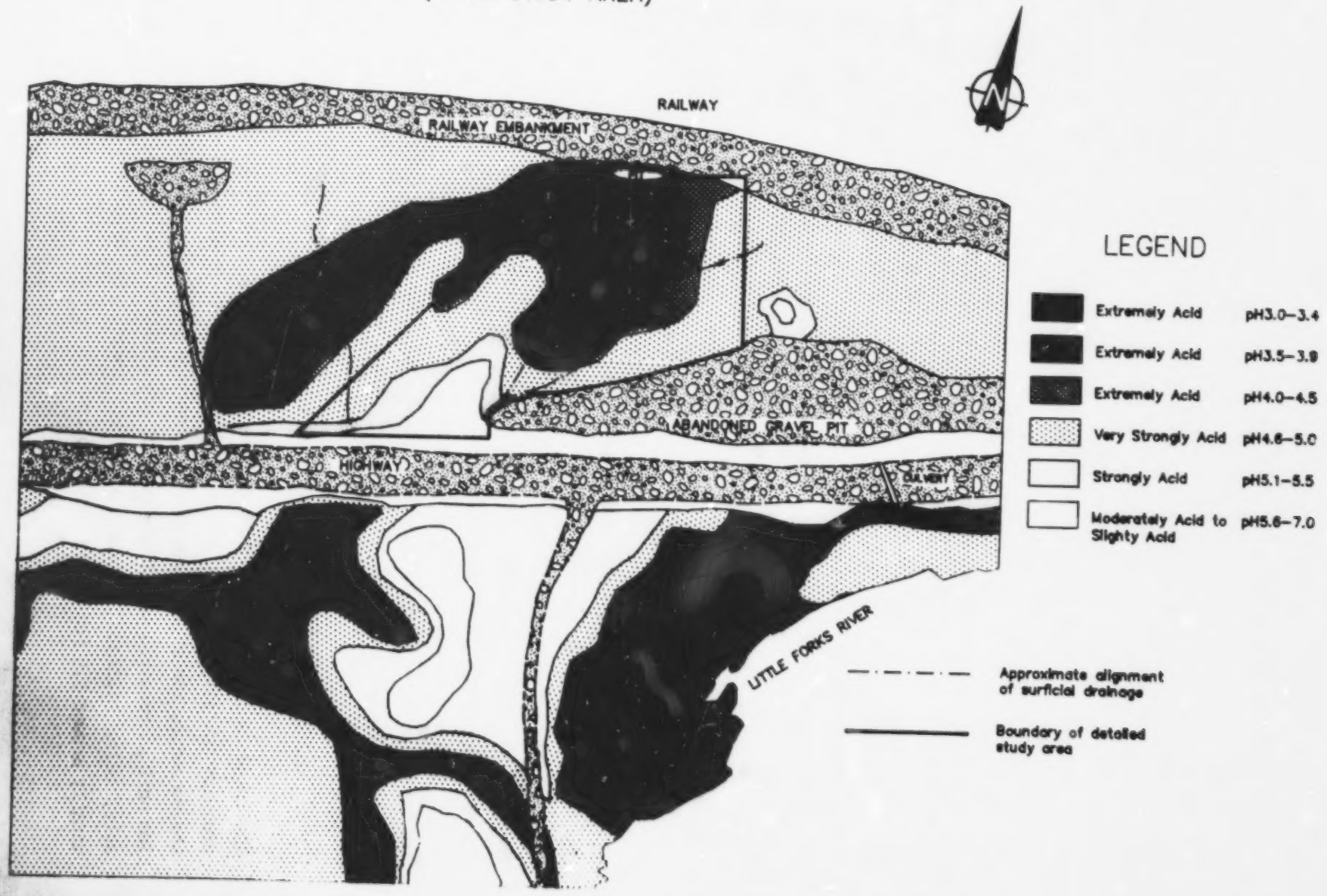


Figure 22

These readings appear to be too low to attribute to natural causes. Thomas and Hargrove (1984) suggest that values much below 4 are obtained only when free acids are present (e.g., H_2SO_4 in cat clays and mine spoils). Even values in the 4.0 to 4.1 range are suspect, and may be indicative of an effect from the acid spill.

Figure 23 shows pH measurements in each of the 25 quadrats in the detailed study area. it can be seen that all of the quadrats (except quadrat J) with soil pH levels of 4.1 or lower were in areas with evidence of total or partial destruction of shrubs after the spill (fill zone, chemically disturbed zone). Only three of the fourteen quadrats in these zones (E, L and O) had soil pH values higher than 4.1 Of these quadrats, one (quadrat L) shows high sodium concentrations, presumably from the drainage of sodium sulphate from the railside pit. These elevated sodium levels have elevated the soil pH. Although it is impossible to know with certainty the pre-spill pH levels in the disturbed quadrats, it would appear that existing pH levels are depressed by at least 0.5 and, in some cases, possibly as much as 1.5 from expected background levels. Thus it seems that there are substantial residual effects on soil pH seven complete growing seasons after the spill. This long lasting effect is not surprising, as the field where the spill occurred has not been actively farmed for a number of years and, consequently, has not been limed since the spill. Under these circumstances, the only significant inputs of basic cations to replace acidity-producing hydrogen and aluminum ions on the cation exchange complex would be from leaf fall. Under such circumstances the replenishment of cations would be a very slow process.

5.6.2 Exchangeable Aluminum

The major soil fertility problem associated with acid soils is potential aluminum toxicity that can arise because of the inverse relationship between the concentration of exchangeable aluminum and pH (Thomas and Hargrove, 1984). The soil pH required to rid the soil of exchangeable aluminum varies considerably, being highest for clay soils and lowest for organic soils. It is usually around 5.5 for most mineral soils.

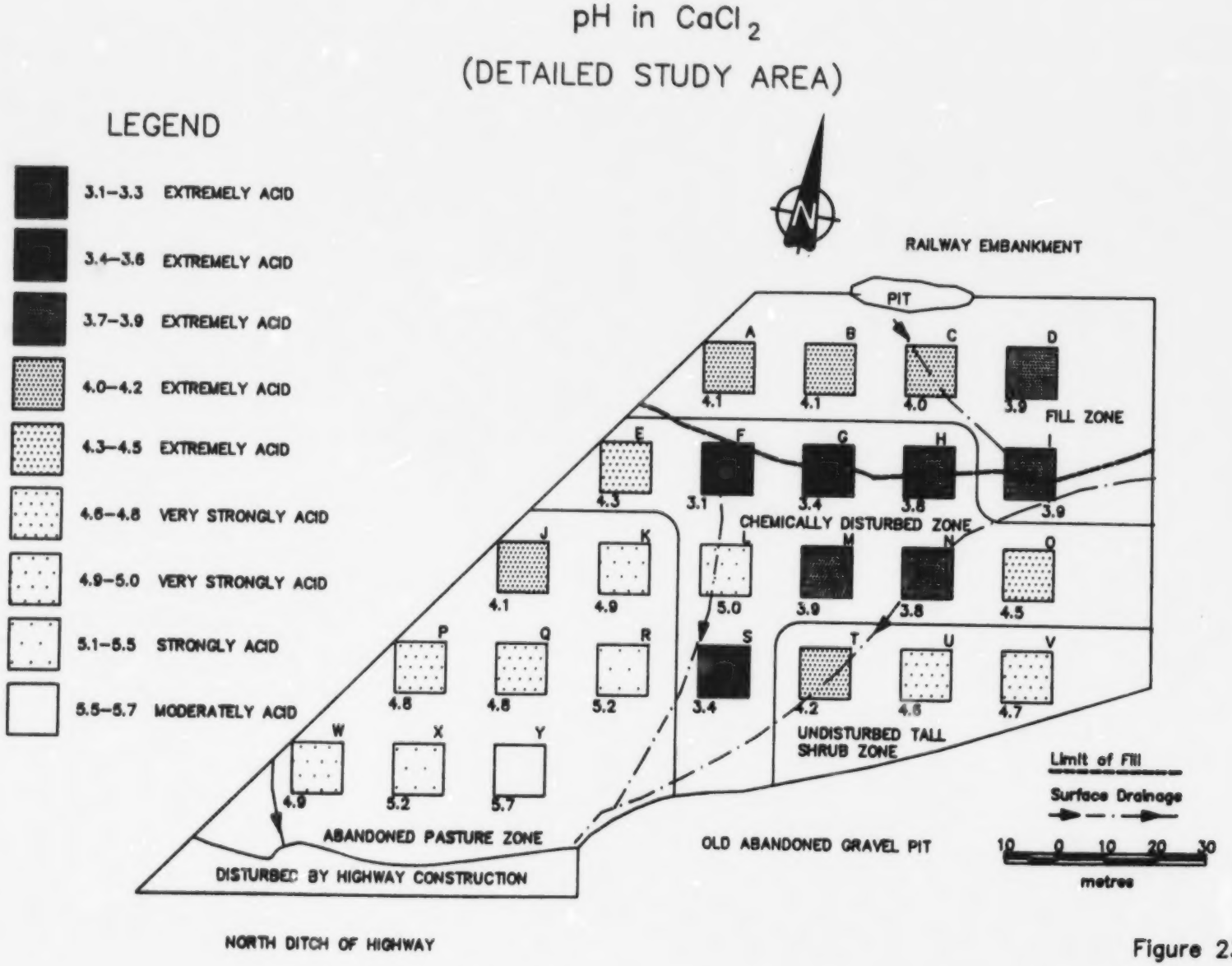

pH in $CaCl_2$
(DETAILED STUDY AREA)
LEGEND
3.1–3.3 EXTREMELY ACID
3.4–3.6 EXTREMELY ACID
3.7–3.9 EXTREMELY ACID
4.0–4.2 EXTREMELY ACID
4.3–4.5 EXTREMELY ACID
4.6–4.8 VERY STRONGLY ACID
4.9–5.0 VERY STRONGLY ACID
5.1–5.5 STRONGLY ACID
5.5–5.7 MODERATELY ACID
N
RAILWAY EMBANKMENT
PIT
A 4.1
B 4.1
C 4.0
D 3.9
FILL ZONE
E 4.3
F 3.1
G 3.4
H 3.8
I 3.9
CHEMICALLY DISTURBED ZONE
J 4.1
K 4.9
L 5.0
M 3.9
N 3.8
O 4.5
P 4.8
Q 4.8
R 5.2
S 3.4
T 4.2
U 4.6
V 4.7
W 4.9
X 5.2
Y 5.7
UNDISTURBED TALL SHRUB ZONE
Limit of Fill
Surface Drainage
ABANDONED PASTURE ZONE
DISTURBED BY HIGHWAY CONSTRUCTION
OLD ABANDONED GRAVEL PIT
10 0 10 20 30
metres
NORTH DITCH OF HIGHWAY

Figure 23

Figure 24 reveals that aluminum concentrations in the detailed study area are low to very low. There is no obvious correlation between aluminum concentration and pH. The lowest aluminum concentration was found in a quadrat that appears to have experienced acidization, contrary to what would be expected on theoretical grounds. Concentrations only marginally lower were found in quadrats with normal pH (e.g., quadrats P and V), and concentrations approaching zero were found in quadrats displaying very low pH (e.g., quadrats F, G and S). It would appear that differences in exchangeable aluminum may be related more to the variability of the soils of the site than to the effects of the acid spill.

The lack of any apparent toxic concentration of aluminum may account for the rapid recovery of the vegetation from the effects of the spill. It appears that normal germination and growth of plants resumed as soon as the pH had risen to levels where plant tissues were not directly attacked.

5.6.3 Titratable Acidity

Titratable acidity at pH 8, as determined by the Barium Chloride-Triethanolamine Method, varied from a low of 5.6 to a high of 23.6 meq/100g, with a mean of 13.6 meg/100g.

These titratable acidity results are a combined measure of exchangeable monomeric Al^{3+}, salt exchangeable H^{+}, weak acid groups of organic matter and hydrolyzable sesquioxides of iron, aluminum and manganese associated with clay minerals or organic matter (Thomas and Hargrove, 1984). They indicate that the major portion of the titratable acidity is pH-dependent rather than of the "permanent" type associated with lattice charges of clay minerals. This is consistent with the coarse-textured, free-draining nature of the soils, which would lead one to expect a low content of clay mineral particles. In light of the low observed concentrations of exchangeable aluminum in even the highly acid samples, it would appear that the titratable acidity is due mainly to organic matter and sesquioxides of iron, which should vary considerably within the detailed study area due to the variability of soils.

EXCHANGEABLE ALUMINUM (Al^{3+})

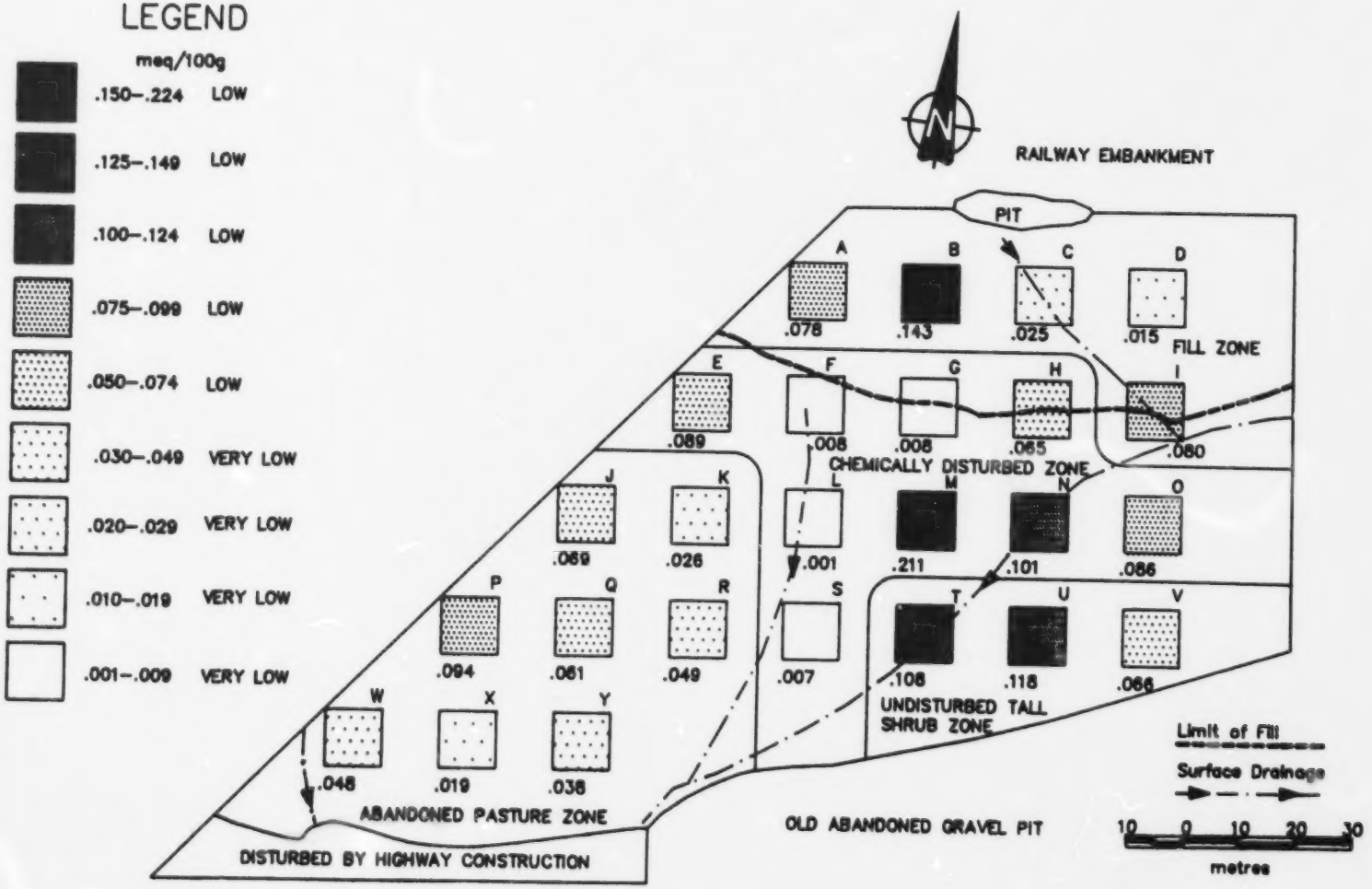


Figure 24

5.6.4 Exchangeable Bases

Measured concentrations of calcium, magnesium, potassium and sodium are listed in Table 8 and shown graphically in Figures 25, 26, 27 and 28, respectively. Sites experiencing acidization should theoretically show lower concentrations of exchangeable bases than comparable non-acidized sites, due to displacement by hydrogen and aluminum ions of exchangeable bases from the cation exchange complex and subsequent leaching of the bases released into the soil water. However, in parts of the study area, the concentrations of sodium might run countercurrent to this trend, as sodium hydroxide was used a a neutralizing agent and a visible deposit of sodium sulphate is still apparent in the pit adjacent to the railway embankment.

Generally speaking, the observed concentrations of exchangeable bases in the detailed study areas were very low, making the differentiation of the effects of the spill from normal variations in background levels a somewhat subjective and imprecise exercise. Some tentative conclusions about the significance of the results are provided below.

The measured concentrations of exchangeable calcium (Figure 25) show both consistencies and inconsistencies with the pH measurements. In the area south of the four quadrats (A, B, C, D) that were covered with a deep layer of imported fill, exceedingly low concentrations of calcium (less than 0.2 meg/100g) were found in areas with exceedingly low pH (4.2 or less). However, similarly low calcium concentrations were also found in certain quadrats with soil pH in the range of background levels (quadrats O, P, R, U and V, with pH readings of 4.5, 4.8, 5.2, 4.6 and 4.7, respectively). A consistent explanation for this phenomenon is not readily apparent.

The data also show that calcium concentrations are depressed along the eastern edge of the detailed study area in quadrats J, P and W in the area designated as the abandoned pasture zone. This data, in conjunction with the presence of the acid-associated Hardhack-Alder plant community on the western edge of the detailed study area and the observation of depressed pH in quadrat J, suggests

EXCHANGEABLE CALCIUM (Ca^{2+})

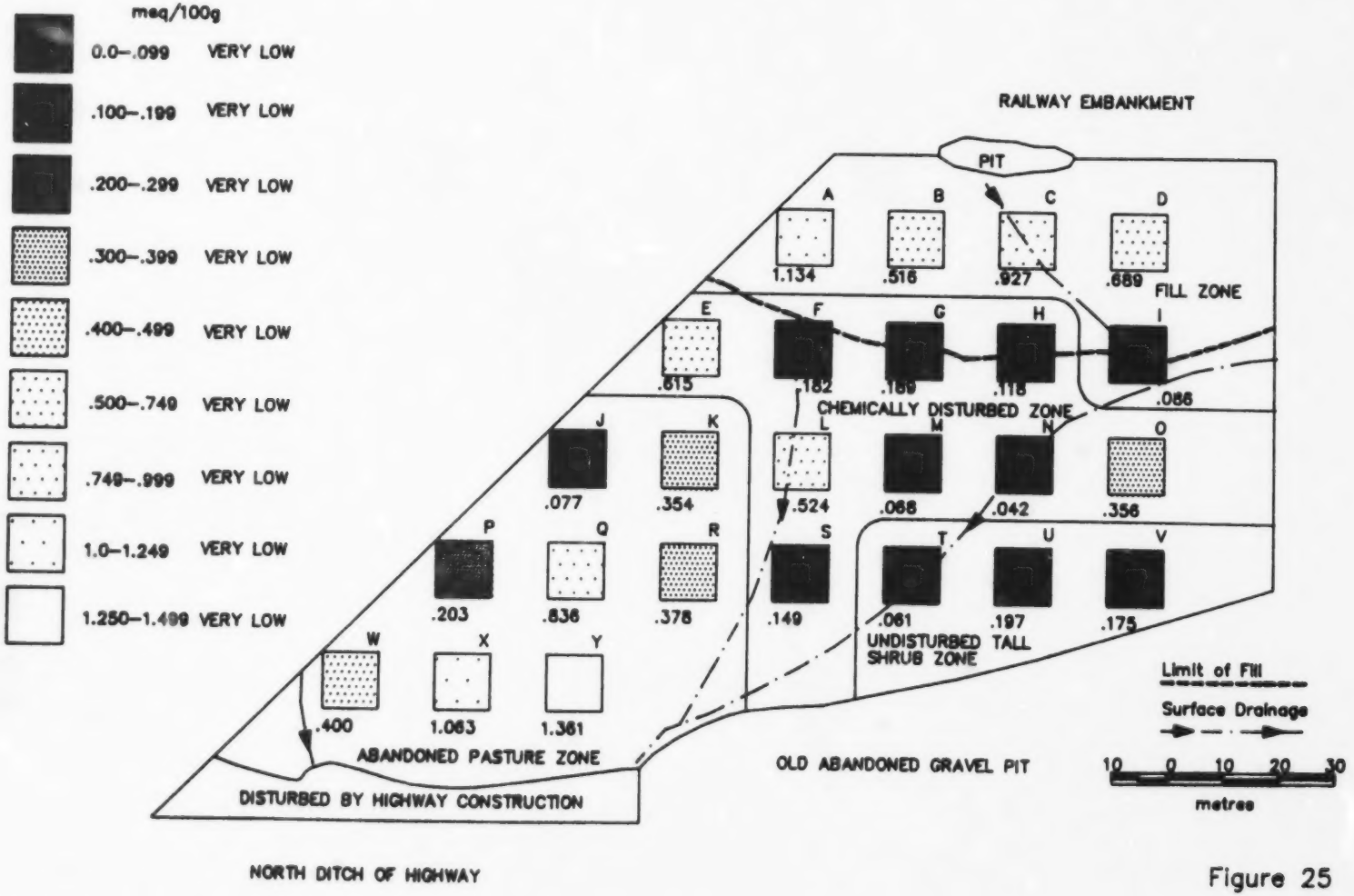


Figure 25

EXCHANGEABLE MAGNESIUM (Mg^{2+})

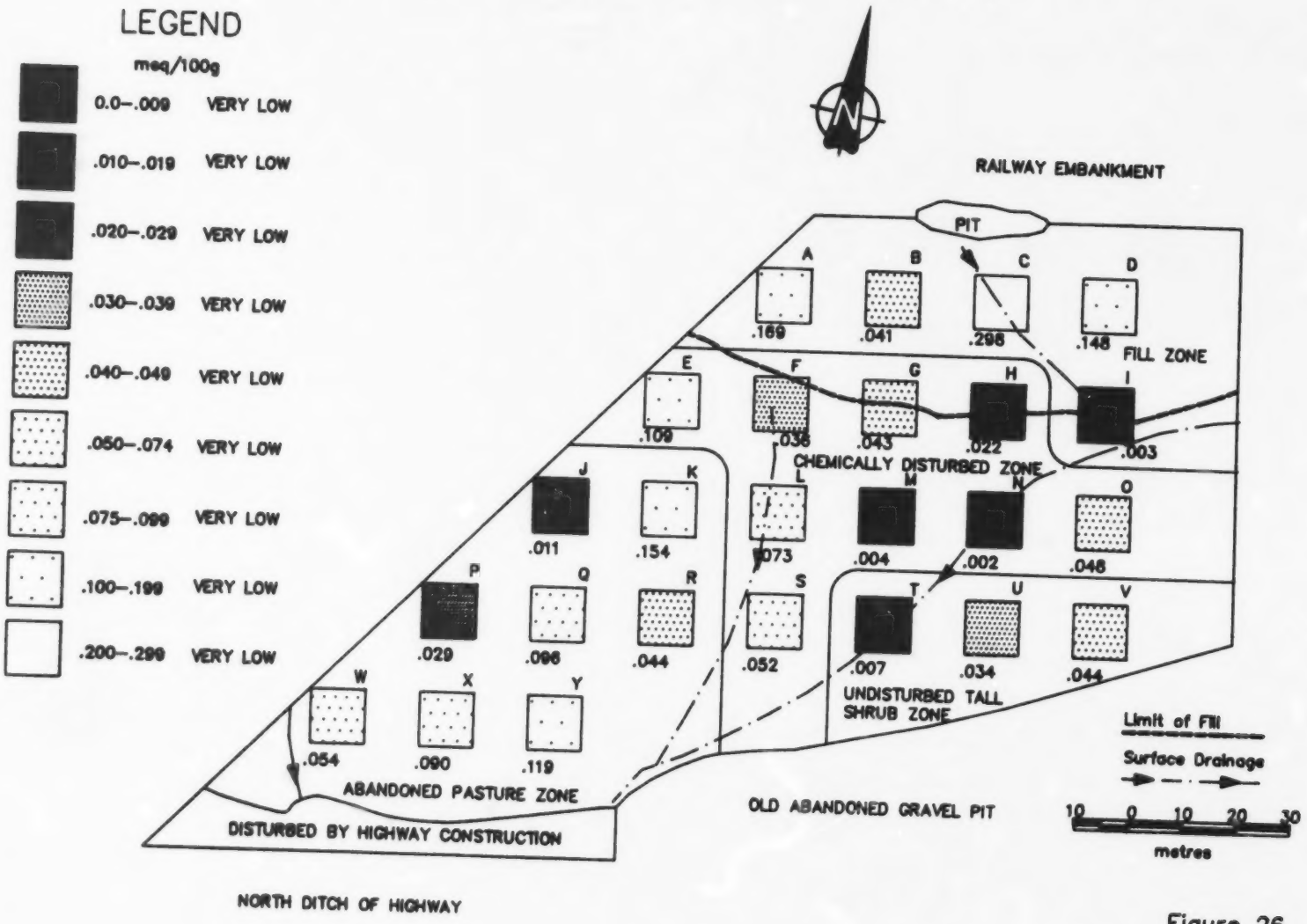


Figure 26

EXCHANGEABLE POTASSIUM (K^+)

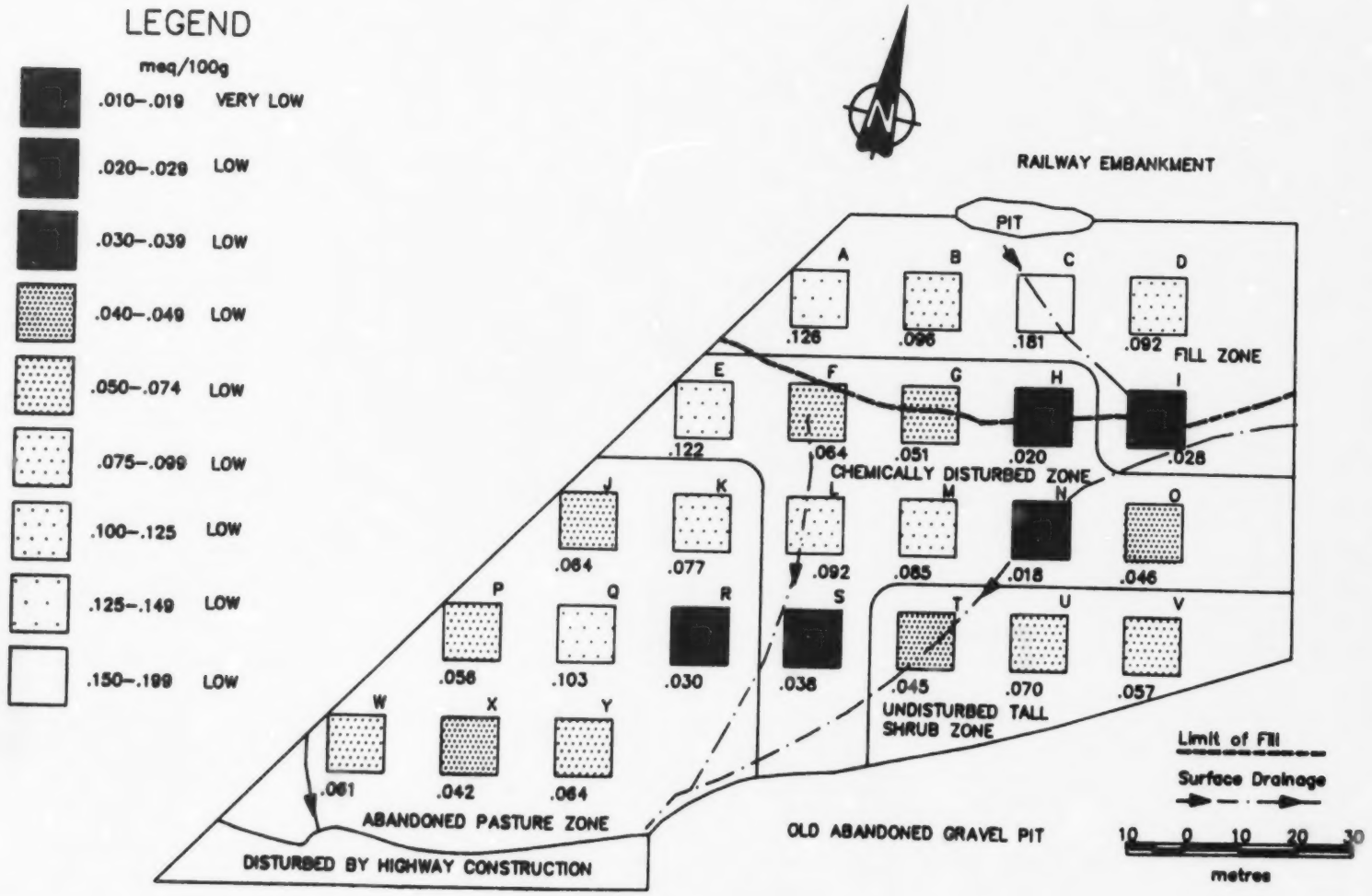


Figure 27

EXCHANGEABLE SODIUM (Na+)

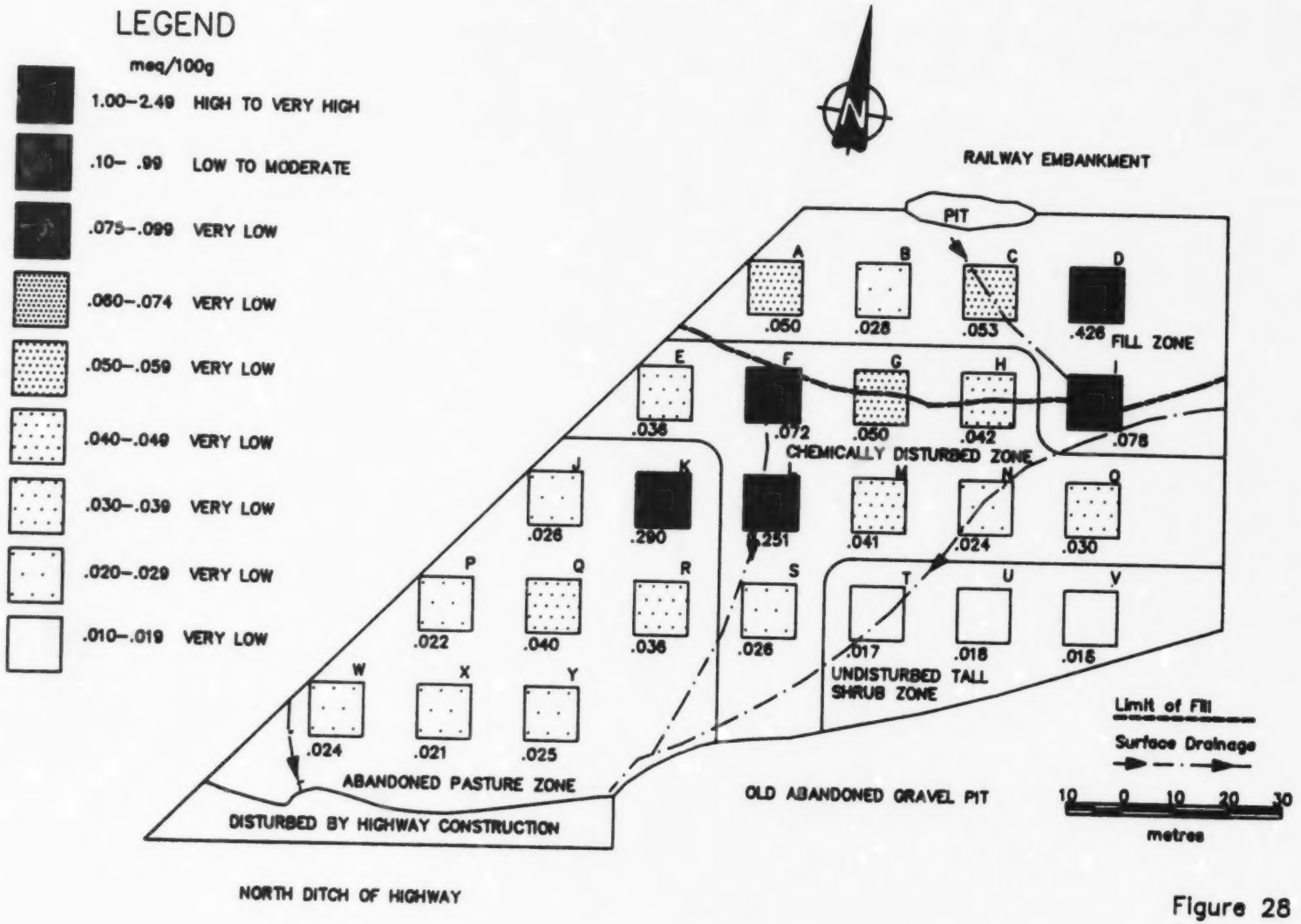


Figure 28

that the effects of the spill may have extended into this area. Similarly, observations of low exchangeable calcium in quadrats U and V (undisturbed tall shrub zone) in the face of seemingly normal pH readings may also suggest a cause and effect relationship with the spill event. However, the location of these latter quadrats on free-draining soils near the edge of a gravel pit may have resulted in very severe leaching which may have also affected exchangeable calcium concentrations.

The fact that calcium concentrations are less depressed in quadrats A, B, C and D along the edge of the railway right-of-way than they were further downslope is not surprising. Although the area adjacent to the railway right-of-way was heavily acidized, it was subsequently covered with a thick layer of fill.

The trend of the data for magnesium is similar to that for calcium, but the pattern is even less pronounced. All concentrations are very low. As in the case of calcium, the lowest concentrations were found in the two acidized zones as well as along the edge of the gravel pit and along the western edge of the study area.

The concentrations of potassium showed no strong trends. Tidsale and Nelson (1975) indicate that there is a complex equilibrium among unavailable, slowly available and readily available forms of potassium which is affected by a number of factors including soil pH. Thus the relationship between a past history of acidization and present concentrations of readily available potassium may not be that direct.

As expected, background levels of exchangeable sodium are typi ally very low (Figure 28). This is consistent with the comments of Tisdale and Nelson (1975) who indicate that sodium is one of the most loosely held of metallic ions, which is readily lost by leaching waters and which would constitute an appreciable part of the suite of exchangeable ions in a humid-region soil only with the continued addition of sodium salts. The isolated instances of significantly elevated concentration of sodium in quadrats L, K and D are

clearly the result of continued inputs of dissolved sodium sulphate from the area of the pit where such deposits are clearly visible. The very high concentrations in quadrat L appear to be related to upwelling from a subsurface source, as this area appears to be the location of a spring.

The elevated levels of sodium did not appear to have any adverse effect on vegetation. Shrub basal area on quadrat L, which had the highest observed sodium concentration, was comparable to that on adjacent quadrats with low concentration of sodium in the soil.

As indicated in Section 5.6.1, the elevated concentrations of sodium in quadrat L appear to have more than counteracted the effect of initial acidization, resulting in a soil pH at or above the expected background level.

5.6.5 Sulphate

Concentrations of sulphate (SO_4^{2-}) are shown in Figure 29. The highest concentrations occur in the chemically disturbed zone. Relatively high concentrations also occur within the fill zone and along the western edge of the abandoned pasture zone. On a coarse scale these trends are consistent with those of the previously presented data. However, when the data is analyzed on a quadrat-by-quadrat basis, a number of questions arise. For example, the quadrats with the highest concentration of sulphate (F, H, I, J, M, N) are not the same quadrats with high values of sodium (D, K, L). Another unexplained phenomenon is the extremely low concentration of sulphate in quadrat S, which displays one of the lowest soil pH values measured in the detailed study area and which was presumably affected directly by the spill.

Tisdale and Nelson (1975) report that the adsorbtion of sulphate increases with decreasing pH; sodium on the other hand is very readily leached at low pH. This could account to some extent for the general lack of correlation between high sodium and high sulphate concentrations. However, a number of inconsistencies, such as the simultaneous occurrence of low pH and low sulphate concentration at quadrat S, are not readily explainable.

SULPHATE (SO_4^{2-})

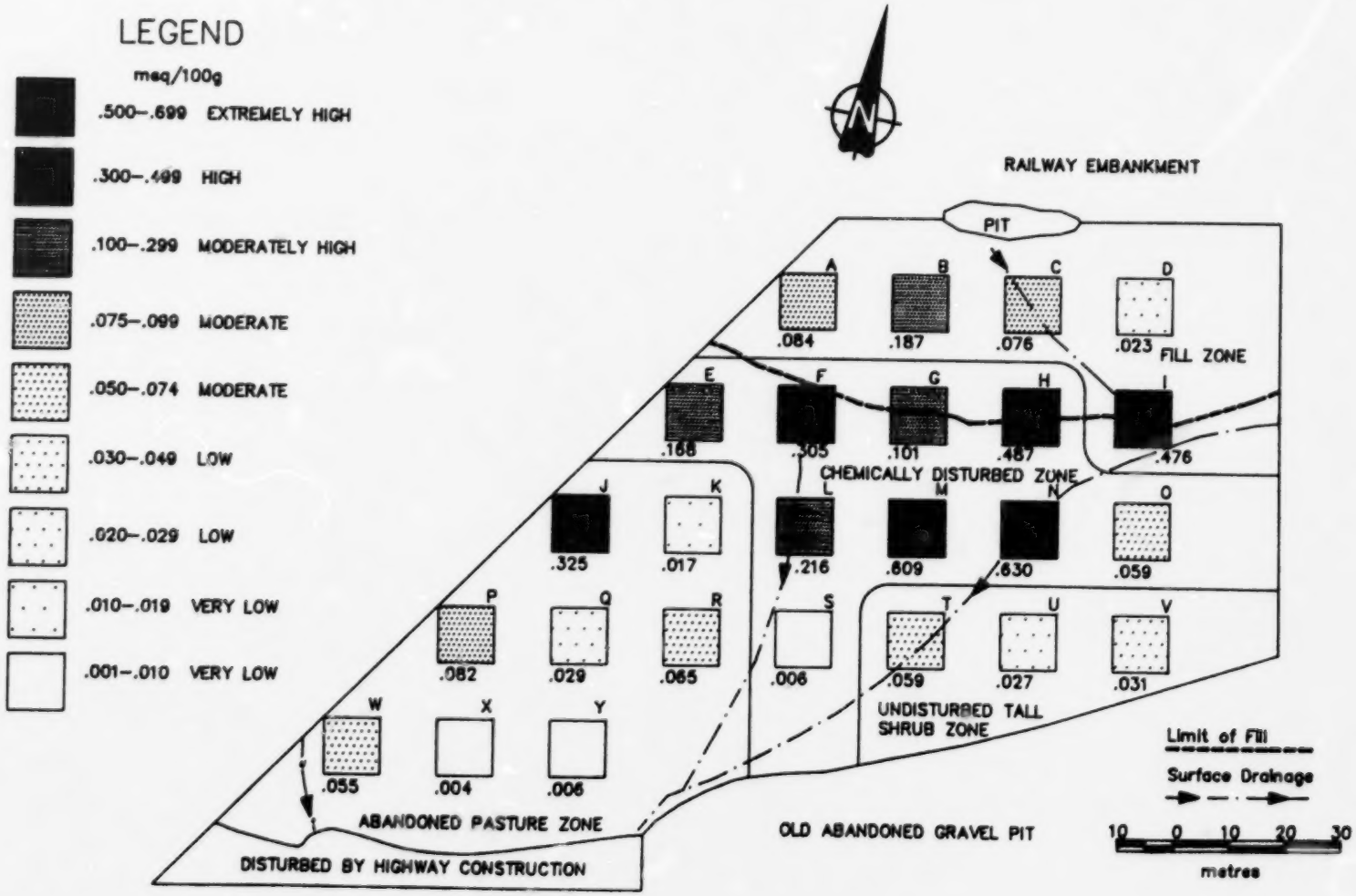


Figure 29

5.6.6 Electrical Conductivity

Electrical conductivity measurements (Figure 30) in all cases fall within the very low range, consistent with the soils and climatic regime of the area. Recorded conductivities were somewhat higher in the fill and chemically disturbed zones than they were in the remainder of the detailed study areas suggesting some correlation with disturbances associated with the acid spill. The highest electrical conductivity reading was in quadrat L, the one displaying the highest sodium concentration.

5.6.7 Cation Exchange Capacity and Percent Base Saturation

Measured cation exchange capacities ranged from 0.187 to 2.941, meq/100g with an average of 0.806 meq/100g. These values are extremely low and indicative of the coarse-grained infertile nature of the soil. They compare with cation exchange capacities of 2 meq/100g reported by Buckman and Brady (1969) for Sasafras sands in New Jersey.

Although cation exchange capacities are low, the percentage base saturation exceeds 80% in the majority of the 25 quadrats in the detailed study area (see Figure 31), indicating that basic cations are relatively available to plants. However, percent base saturations lower than 80% occur in 7 quadrats (H, I, J, M, N, P, T with values of 75.7, 70.9, 72.1, 48.4, 46.0, 76.7 and 54.6 percent, respectively). In all of these cases the lower percentage base saturations are associated with higher than average concentrations of exchangeable aluminum occurring in conjunction with lower than average concentrations of exchangeable bases. As in the case of most of the other soil chemistry data, there is no clear and consistent relationship between percentage base saturation and the past history of acidization of the site. Moreover, no clear relationship between percentage base saturation and the success of shrub recolonization and growth is evident.

ELECTRICAL CONDUCTIVITY

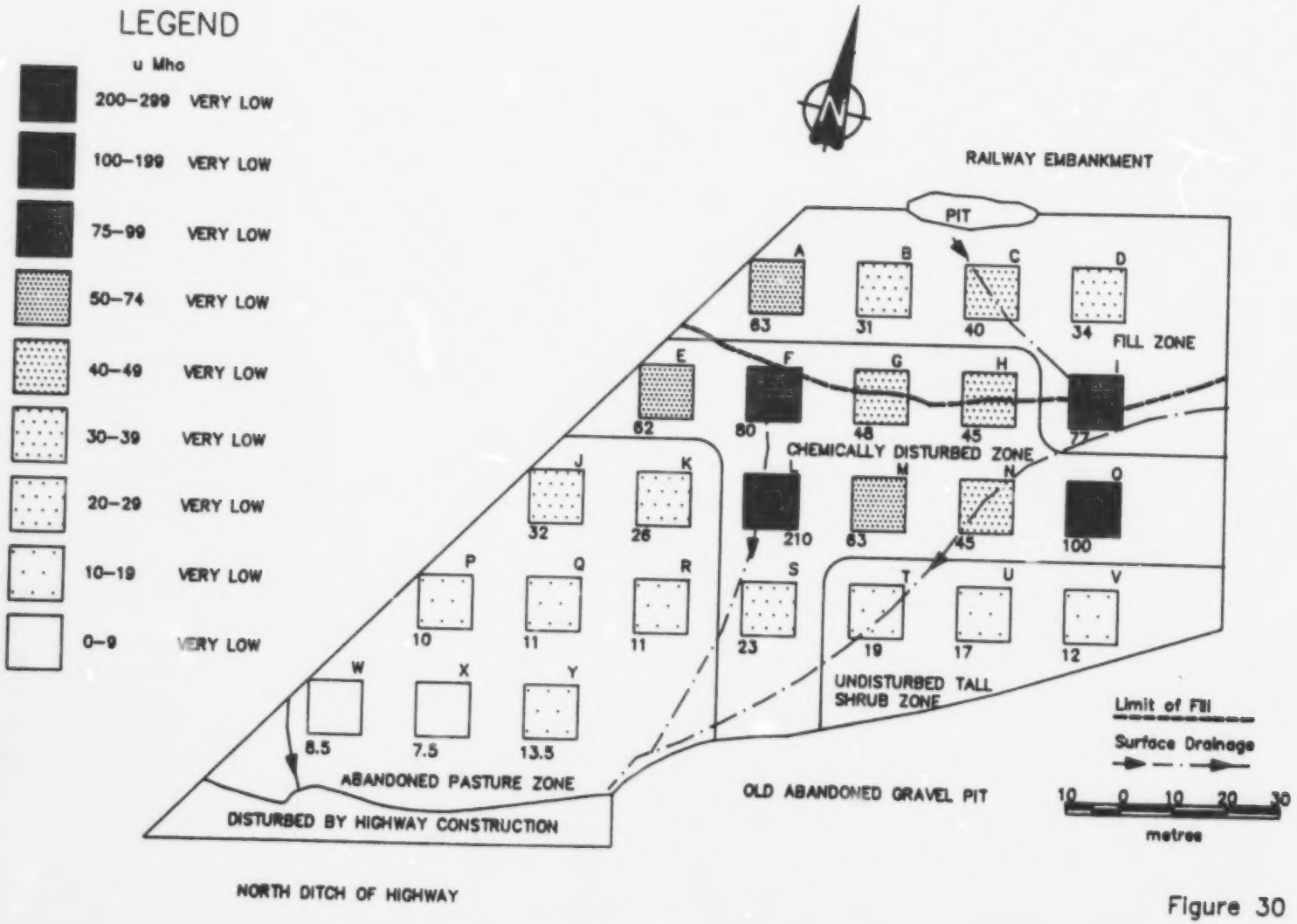


Figure 30

PERCENT BASE SATURATION.

$$\left(\frac{\Sigma\ Ca^{++},\ Mg^{++},K^{+},Na^{+}}{\Sigma\ Al^{+++},\ Ca^{++},\ Mg^{++},K^{+},Na^{+}}\right)$$

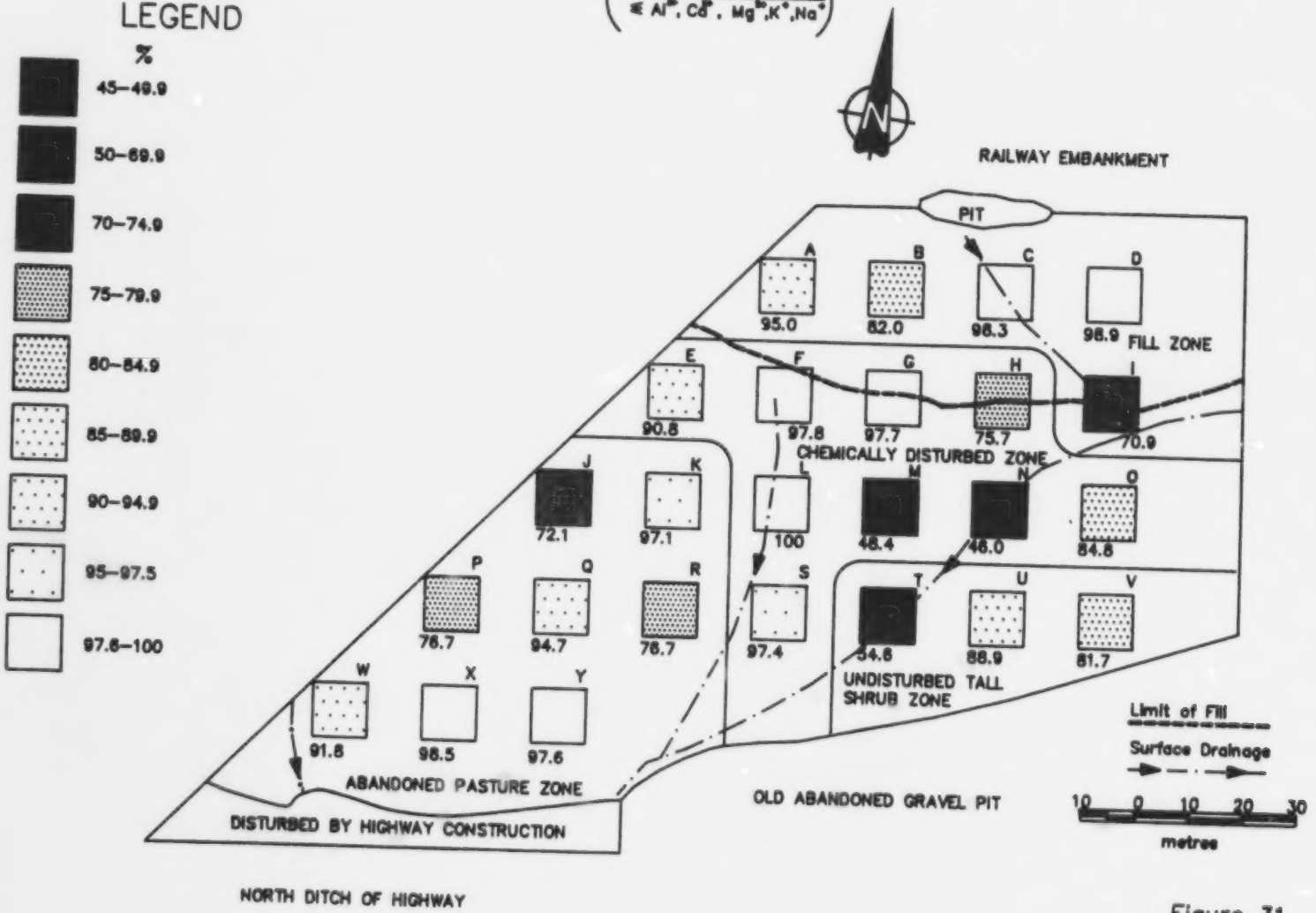


Figure 31

5.7 CLUSTER ANALYSIS OF SOILS VARIABLES

Statistical analysis of the chemical and drainage data for the soils in the 25 quadrats established four identifiable clusters of quadrats (Figure 32):

1) Quadrats J, K, P, Q, R, W, X, Y which conform exactly with the abandoned pasture zone identified during the vegetation studies.

2) Quadrats O, T, U, V which conform roughly with the undisturbed tall shrub zone identified during vegetation studies.

3) F, G, in the chemically disturbed zone.

4) H, I in the chemically disturbed zone.

Elsewhere in the fill zone and the chemically disturbed zones, the statistical techniques employed did not identify any consistent pattern. This is not totally unexpected in the light of the heterogeneity of soil conditions in this area, coupled with the seemingly uneven distribution of spill-related effects.

5.8 INTEGRATED CLUSTER ANALYSIS OF VEGETATION AND SOILS DATA

The results of the cluster analysis of the combined set of vegetation and soils data is shown in Figure 33. This analysis shows areas corresponding approximately the abandoned pasture zone, the undisturbed shrub zone and the fill zone. Again no pattern is revealed in the area designated as the chemically disturbed zone. This is a reflection of the observed lack of a consistent pattern among the many chemical and biological parameters observed in this area. This lack of consistent pattern is likely the result of the superimposition of the heterogeneity of the area, the non-uniformity of the original impacts and the extensive process of natural recovery that has occurred since this spill.

RESULTS OF CLUSTER ANALYSIS OF SOILS VARIABLES.

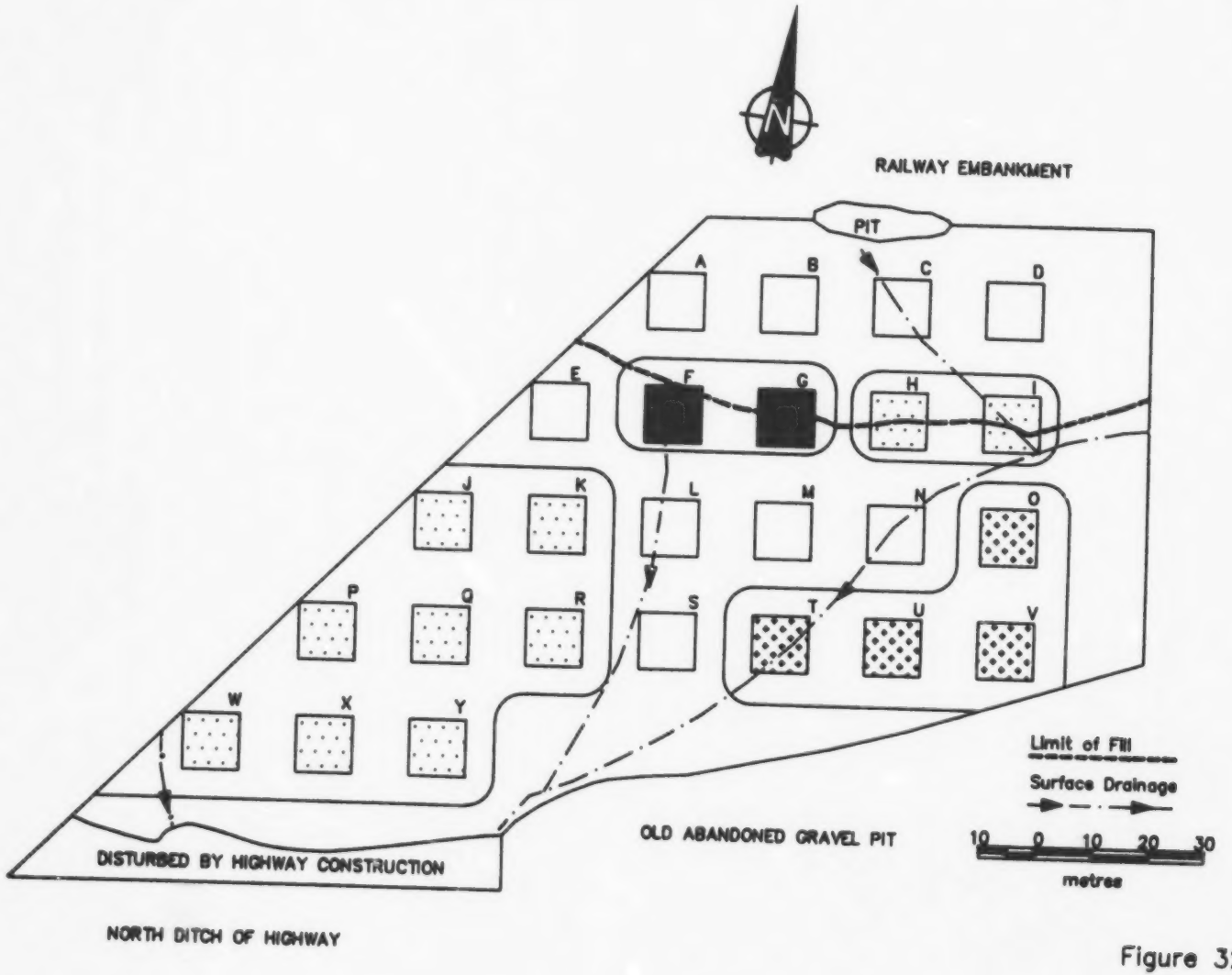


Figure 32

RESULTS OF INTEGRATED ANALYSIS OF VEGETATION AND SOILS DATA.

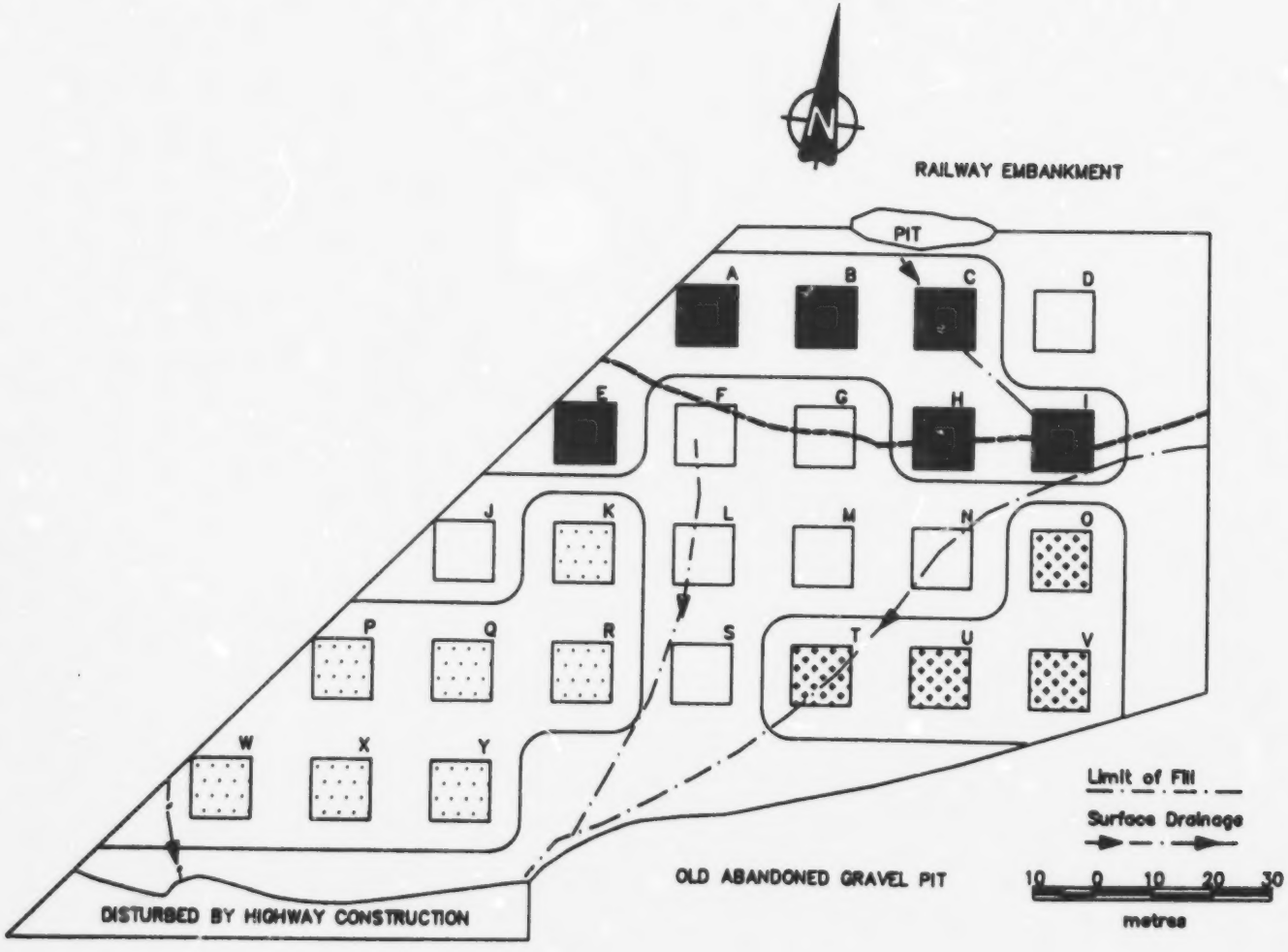


Figure 33

5.9 SUMMARY

Because of the length of the preceding discussion, the following brief summary is provided to highlight the main finding of the field program.

1) The grid selected for detailed study is centred on the main area of the spill.

2) Eight communities were identified within the detailed study area. Of these, four communities are associated with the normal process of succession on the site (Abandoned Pasture → Hardback-Sweetfern→ Hawthorn-Black Cherry → Open Woodland). Three communities are associated with the invasion of bare mineral soil after a disturbance such as a soil excavation or fill placement (Sweetfern, Goldenrod, Bentgrass-Goldenrod). One community (Hardhack-Alder) was consistently associated with areas with standing dead stems of Hawthorn and appears to be the community diagnostic of areas that were acidified, but not otherwise disturbed.

3) On the assumption that the Hardhack-Alder community is diagnostic of past acid disturbance, it would appear that a small area directly west of quadrats E and J was probably affected by the spill, but did not get included in the sampling.

4) Prior to the spill, all of the detailed study area, with the exception of quadrats J, K, P, Q, R, W, X, Y in the southwest corner of the detailed study area, was vegetated in relatively mature Hawthorn. At the time of the spill, the southwest corner of the study area was an abandoned pasture with only isolated clumps of Hawthorn.

5) Within the 17 quadrats formerly occupied by shrubs, total mortality of shrubs occurred in 11 quadrats (A, B, C, D, E, F, G, H, I, L, S). In 3 quadrats (M, N, O), some of the shrubs survived and in 3 others (T, U, V) all of the shrubs survived.

6) Quadrats A, B, D, C and I, located in the immediate spill area were covered with a thick layer of fill. Reestablishment of vegetation on this fill has generally been extremely poor.

7) Gray Birch (Betula populifolia), Downy Alder (Alnus crispa) Beaked Willow (Salix bebbiana) and Pin Cherry (Prunus pensylvanicus) are the principal species that invaded areas disturbed as a result of the spill. Their success in becoming establish has generally been poor on the fill zone and quite good on quadrats which were acidified, but not disturbed in any other way.

8) Very little germination of shrubs took place for two growing seasons after the spill. In quadrats where shrubs were affected but not killed, growth was significantly depressed for two growing season and usually recovered significantly in the third growing season. After four growing seasons, growth rates of shrubs were comparable on acidified and non-acidified quadrats.

9) Ground vegetation species found on acid disturbed quadrats were those that would be expected to invade any disturbed site. This would indicate that the spill did not create any serious toxicity effects. This is confirmed by the absence of significant invasion by highly acid tolerate or salt tolerant species.

10) Most of the quadrats, which were determined from vegetation evidence to have experienced acid spill related damage, still display depressed soil pH, ranging from about 0.5 to 1.5 below expected background.

11) Concentrations of exchangeable aluminum, which can be very high in acid soils, were low to very low, probably reflecting the paucity of clay particles in the soil.

12) The concentration of exchangeable bases was extremely low, in keeping with the high permeability and low clay content of the soils and the relatively

high precipitation. In the chemically (and not physically) disturbed zone, exchangeable calcium was lowest where pH was lowest. However, low calcium concentrations were also found outside of the zone of obvious acid damage. The significance of these measurements and their lack of correlation with pH is not clear. The pattern of correlation of exchangeable base concentration with pH becomes progressively less distinct for magnesium and potassium.

13) Three quadrats displayed exchangeable sodium concentrations significantly elevated from the general backgrounds. These elevated sodium concentrations must relate the continuing effect of the leaching of residual soluble sodium sulphate (the product of neutralizing the acid).

14) There was a hundredfold variation in the concentration of sulphate in the soils of the detailed study area. Of the nine quadrats in the chemically disturbed zone, four had high to extremely high concentrations and three had moderately high concentrations. Only one very low reading was recorded in this zone, in quadrat X. This latter result was somewhat unexpected as the pH at quadrat S was the third lowest recorded in the study area. Concentrations of sulphate in the fill zone ranged from low to high. This variability in the data is consistent with the masking effect associated with placing of variable thickness of fill over the area. Only one high sulphate concentration (in quadrat J) was noted in the area where there was no physical evidence of vegetation damage. This is consistent with the relatively low pH and low magnesium concentration also observed in this quadrat and the presence of a Hardback-Alder vegetation community bording this community, all of which suggest that this area was affected by the acid spill.

15) There was very little correlation of high concentrations of sodium and sulphate. This in presumably due to the fact that adsorption of sulphate increases with decreasing pH, whereas sodium is very loosely held at low pH.

16) The cation exchange capacities of the soils affected by the spill were extremely low. However, only 7 of the 25 quadrats exhibited a percentage base satuation less than 80 percent, indicating that nutrients, although scarce, were available to plants. Cation exchange capacities lower than 80 percent were always the result of higher than average concentrations of exchangeable aluminum coupled with lower than average concentrations of basic cations. However, in no instances did aluminum concentrations even approach potentially toxic levels. Plants occupying the site showed no signs of aluminum toxicity or deficiencies in basic cations.

6. DISCUSSION

6.1 LESSONS LEARNED FROM THE SPRINGHILL SPILL

The follow-up studies of the Springhill Spill revealed that the long- term effects of a sulphuric acid spill on land were not serious in an area of high precipitation and coarse-grained, free-draining, nutrient-poor soils. Although the spill appears to have resulted in a long-term lowering of soil pH in the area that came in direct contact with the acid, as well as somewhat capricious effects on the nutrient status of the soil, these effects do not appear to have seriously impaired the recovery of vegetation on the site. The neutralization with sodium hydroxide is responsible for the present elevated sodium concentrations in a very limited area, but has not proven to have been either particularly harmful or beneficial to the long-term recovery of the site.

In contrast to the above, the physical disturbance created by bulldozing access to the site and the placing fill over acidized areas has created very poor conditions for the re-establishment of vegetation. This physical disturbance remains as the most significant long-term impact of the spill seven growing seasons after the event.

It is fairly clear that the "no action" alternative would have been the environmentally preferable one in the case of the Springhill Spill. Although the application of sodium hydroxide as a neutralizing agent to a portion of the released acid undoubtedly reduced the total amount of acid flowing on or through the soil, the long term benefit was not that great, as evidenced by the fact that sites which experienced the full brunt of acidization show no major residual ill effects at present. The preferred course of action would have been to allow the acid to percolate into the soil and to subsequently apply agricultural lime (crushed dolomite) to the intact natural ground surface to restore normal pH and to replenish calcium and magnesium on the cation exchange complex. The removal of dead stems of trees and shrubs could also have been undertaken for aesthetic reasons, although this would not be necessary on ecological grounds.

The major environmental impacts and response costs associated with the Springhill Spill were the result of treating the spill as an immediate threat to the environment, which it was not. In this case a more leisurely planned fertility restoration program would have been environmentally preferable and more cost-effective than the course of action taken.

It is, of course, always easier to know what should have been done with the benefit of hindsight. In this particular case, there were undoubtedly concerns about how far the acid would travel through the soil, concerns about contamination of the nearby Little Forks River and concerns about public safety. In addition, some of the terrain disturbance south of the tracks was related to the removal of train wreckage and the protection of the railway personnel engaged in this work, and may not have been totally avoidable.

6.2 LESSONS LEARNED FROM OTHER SPILLS

There is very little specific documentation in the scientific literature on the environmental effects of acid spills. However, a large and expanding body of literature exists on the sensitivity of various aquatic organisms to acidic conditions. This includes laboratory data on lethal and sub-lethal concentrations. A cross-section of this type of data is provided in the ENVIROTIPS publication on Sulphuric Acid and Oleum (Canada Environmental Protection Service 1984). The data base on sensitivity of aquatic organisms will continue to expand rapidly as a result of ongoing research into the effects of acid rain.

We were unable to uncover any documentation of the effects of acid spills on terrestrial systems. However, there is an extensive body of literature on soil acidization because of its importance to agricultural productivity. Standard references such as Tisdale and Nelson (1975) and Adams (1984) provide excellent overviews of soil acidity problems, based on research results published in hundreds of scientific papers. The conclusions reached from analysis of these documents is that soil acidization is a totally reversible phenomenon that can be dealt with effectively by established agricultural practices.

A number of acid spill accidents were examined to obtain an appreciation of the types of countermeasures that have been used during previous spills. These reports included an April 16, 1975 Environment Canada memorandum dealing with a sulphuric acid near North Bay, Ontario; a June 9, 1985 Ontario Ministry of Environment report on a second spill in the same general area; a report on a major spill of concentrated sulphuric acid from a storage tank at a mine near Murdochville, Quebec (Moulins and Pannell 1983) and two U.S. National Transportation Safety Board (1985a,b) accident reports, dealing with a leak from a waste acid truck in Orange County, Florida and leak from a railway tanker of concentrated nitric acid in Denver, Colorado. In addition to the accident reports, newspaper clippings on these and other spill accidents were also evaluated. The following facts were distilled from these various sources:

1) During the first North Bay incident a series of dams were constructed on a creek to hold up acidized water before it reached an important spawning stream (Wasi River). Soda ash (Na_2CO_3) was dumped upstream of the dams and 50% liquid caustic sod (NaOH) was used to neutralize aridized water in the pools upstream of the dams. During these operations pH levels as low as 3 and as high as 12.5 were experienced in the Wasi River. Final restoration was accomplished by spreading crushed limestone on areas that had been affected by the spill.

2) During the second North Bay incident acid again escaped into a tributary of the Wasi River. Again dams were constructed. Hydrated lime ($Ca(OH)_2$), 35% limestone slurry, quicklime (CaO) and soda ash (Na_2CO_3) were used as neutralizing agents. An extensive pH monitoring program was conducted while response measures were being undertaken. During this time, pH measurements taken in the Wasi River ranged from a low of less than 2 to a high of 11. After the spill emergency was over, crushed limestone was spread on streambanks to handle residual acidity.

3) During the escape of 3600 tonnes of concentrated sulphuric acid into the watershed of the York river near Murdochville, Quebec, a variety of neutralizing agents were used including 50% caustic soda ($NaOH$), slaked lime ($Ca(OH)_2$), soda ash (Na_2CO_3) and crushed limestone. Because of the occurrence of the spill within an industrial complex, better control of pH was achieved than in the previously described incidents. The control of pH was particularly critical because of the release of soluble copper compounds at low pH and the presence of Atlantic Salmon within the watershed. The use of calcium compounds for neutralization created some problems in the aquatic environment, as gypsum precipitated during the neutralization covered streambeds, affecting the habitat quality for invertebrates.

4) In the railroad car incident in Denver involving a load of nitric acid, several inches of soda ash ($Na_2 Co_3$) were spread over the spill using a snow blower. The residual material was trucked to a disposal site. Since the incident occurred in a railyard, there were no long-term environmental implications.

5) In the tanker truck incident in Florida involving a load of mixed acid, the spill was diked. "Oil-Dri" absorbant material was added to the acid and the solidified material was mixed with soda ash (Na_2CO_3) and hauled off site. This sequence was followed because a lab test of a neutralizing procedure using sodium carbonate and a field test using agricultural lime produced extensive foaming.

6) Powdered lime was used on a spill 200 tons of concentrated suplhuric acid from a highway tanker near LaLoche, Saskatchewan (Prince Albert Herald, May 7, 1981). The form of the lime ($CaCo_3$, $Ca(OH)_2$, CaO) was not specified in the article.

It can be seen that a variety of substances have been use historically as neutralizing agents including:

soda ash	Na_2CO_3
caustic soda	NaOH
crushed limestone in both powdered and slurry form	$CaCO_3$
slaked lime	$Ca(OH)_2$
quicklime	CaO

There has been a tendency to use substances which effect rapid neutralization. This frequently results in overdosing problems, which may cause the pH of nearby streams to rapidly fluctuate from very low levels to very high ones. This is particularly problematic when caustic soda is used as a neutralizing agent in less than perfectly controlled circumstances. It is also noteworthly that the response measures in the two North Bay spills did not prevent an initial drop in the pH of the stream. Thus the initial pH shock had already occurred when remedial action commenced, a situation that should be considered the rule rather than the exception. Under these circumstances the overdosing caused by the use of strongly alkaline substances might have further stressed surviving organisms. A more gradual rise in pH to the neutral range would have probably been environmentally preferable.

The accident reports shed little light on impacts or mitigation of impacts on the terrestrial environment.

6.3 RECOMMENDATIONS OF OTHER RESEARCHERS

Mercer et al. (1978) recommended the use of weakly basic agents for the in situ neutralization of acid to avoid overdosing problems. They recommended the use of powdered limestone or sodium bicarbonate to keep the pH of a treated spill residual below nine, regardless of how much excess is applied. They maintain that the combination of strong oxidants and reductants will normally require a reaction tank operated under controlled conditions to avoid releasing excessive quantities of the reactants.

A number of authors have also suggested the use of sorbants or gelling agents to immobilize acid spills and reduce the fuming and frothing problem that accompanies their neutralization. This technique was in fact used in the Orange County, Florida spill described previously. Materials suggested have included flyash (Pilie et al. 1975), Universal Sorbant Material (Temple et al 1978), and a number of substances described in Braley (1982) aimed at either forming a skin over or solidifying the spill (polymethyl methacrylate, polyacrylamide, anhydrous sodium sulphate, absorbent clay (eg: Oil-Dri, Sorboil), polycarbonate, expanded perlite, silicone oil, sulfonated oil, fire fighting foam, vermiculite). A number of these substances may be of practical value in industrial situations where chemicals can be kept close at hand, but we believe that they are of marginal value in major transportation - related spills where large quantities of readily available and inexpensive materials are required. It should also be noted that they create additional residues which must be removed from the site and safely disposed of. Thus they increase the physical disturbance of soils and vegetation in the spill area.

6.4 STUDY TEAM RECOMMENDATIONS

Although each spill situation will differ substantially, the recommended overall plan of attack is as follows:

1) Ensure that sufficient security arrangements are in place to protect the public.

2) Establish the trajectories of flow of acid and acid contaminated water and identify the locations where they can be most effectively intercepted.

3) Establish what men, equipment and materials are available and formulate an immediate response plan to use these resources in the most effective manner.

4) Establish a pH monitoring network.

5) Consult with local experts in aquatic biology, hydrogeology, forestry and soils, as required.

6) Implement the immediate response plan.

7) Document the location of the spill using a survey crew.

8) Set up a long-term restoration plan if it proves desirable.

9) Design and execute the long-term restoration plan.

6.4.1 Security Considerations

The institution of adequate security arrangements removes some of the pressure on the spill response team to take dramatic action which, upon deeper reflection, might prove detrimental to the environment. Therefore, keeping the public away from the spill site benefits both public safety and environmental protection.

6.4.2 Spill Trajectories

In most spills the key short-term priorities will be to determine whether there is a threat to the aquatic environment, to establish the nature and magnitude of that threat and to plan and implement appropriate responses. A rapid and accurate evaluation of acid spill trajectories and natural drainageways is essential to these short- term goals.

6.4.3 Available Resources and Immediate Response Plan

The immediate spill response will have to take into account men, materials and equipment that are available within a reasonable distance of the spill. Although there may be an ideal way to handle each particular spill situation, compromises will have to be made in the light of the resources that are actually available. For example only a limited range of neutralizing

chemicals and equipment may be close enough to the spill to be of practical value for the immediate response. In addition to requirements for conventional equipment such a bulldozers, frontend loaders, backhoes and dump trucks, consideration should be given using concrete mixers, whitewash equipment and pumps for mixing and applying neutralizing solutions. Consideration should also be given to adaptation of agricultural equipment, such as lime spreaders, and highway maintenance equipment, such as sand spreaders and snowblowers for the spreading of powdered neutralizing agents.

6.4.4 pH Monitoring

It is imperative that a pH monitoring network be established prior to the start of major response operations to ensure that the response measures are having the desired effect. This is particularly critical when strong bases such as caustic soda are used for neutralizing acid, and there is a major risk of overdosing.

6.4.5 Expert Advice

It is highly beneficial to have experts in the areas of aquatic biology, forestry, hydrogeology and soils available for consultation prior to the initiation of major countermeasures. To facilitate this, a roster of experts in each region of Canada should be identified in advance and should be on call during spill emergencies.

6.4.6 Implementation of Immediate Response Plan

The immediate response should concentrate on the protection of resources at immediate risk. These will typically be aquatic organisms. In certain cases there may also be immediate issues with groundwater and specimen trees.

Immediate response actions should include the installation of barriers or sumps to contain or intercept the spill, where appropriate; the removal or treatment of pooled acid; and the treatment of acid-contaminated runoff. In

the light of the poor experience in neutralizing acid spills with strong bases such as sodium hydroxide, it is recommended that weakly basic solutions of slaked lime (limewater), sodium bicarbonate or washing soda in water be used as neutralizing agents on both concentrated and dilute acids. These could be mixed in conventional concrete mixers or whitewashing equipment, which is available in most parts of the country. Slurries of limestone, quicklime and slaked lime in water could also be mixed and applied in a similar manner. When using lime slurries, the effect of particle settlement on stream and lake bottom invertebrates should be considered. Also, when using any calcium based compound, even in solution form, the effect of the relatively insoluble gypsum ($CaSo_4$) precipitate resulting from neutralization must be considered.

Crushed limestone/dolomite is effective for neutralizing pools of concentrated acid. However, it gives rise to a severe frothing problem which may create difficulties for field crews.

If there is no immediate threat to the environment, it is debatable whether in situ neutralization of pools of acid is either necessary or desirable. In situ neutralization will create substantial deposits of soluble sodium sulphate ~~or poorly soluble gypsum~~ (Na_2SO_4) which may have to be removed or buried, increasing the level of disturbance. In many cases it would be preferable to pump any accessible pooled liquid into storage containers and deal with the effects of the acid that has percolated into the soil in the long-term site restoration plan.

If the spill has occurred in an area of fine-grained agricultural soils, the use of sodium-based neutralizing compounds should be avoided. These cause dispersion of clay-sized particles, which can potentially result in a deterioration of soil structure. In agricultural areas it is preferable to limit emergency response to the containment of acid and the removal of pooled acid to tank storage. Immediate treatment of the soil without proper advice and planning could prove harmful to both the structure and fertility of the soil. Even when calcium-based neutralizing agents are used, there is a danger of over-liming or of creating an imbalance among the principal enchangeable cations (calcium, magnesium and potassium).

A sulphuric acid spill would not normally constitute a major threat to sources of groundwater, unless the aquifer were in a formation containing potentially toxic compounds, such as those containing arsenic or cadmium, which might become more soluble at low pH. It would be advisable to monitor nearby wells for complaints about taste and to run periodic tests of pH. If low pH readings are encountered, tests for potentially toxic compounds in the well water should be run if there is any history of this type of problem in the area.

Another type of subsurface effect that may require prompt action is the protection of valuable shade trees. A serious threat to such specimen trees is quite conceivable in the event of a spill from either a highway or railway tanker in either an agricultural or urban area. Since the aesthetic and economic value of such trees may be extremely high, extraordinary measures may be warranted to save individual trees. In such cases consideration should be given to the use of root feeding devices to carry a mildly basic solution into the root zone to neutralize acid flowing below the soil surface. The design of the injection system and the control of dosage rate would be extremely critical and would best be handled by a specialist in tree physiology. This type of individual should be on the roster of specialists identified in advance for each region.

6.4.7 Documentation of Spill Location

Follow-up monitoring of acid spills as well as settlement of claims for restoration or compensation would be greatly facilitated by the preparation of a reproducible survey of the accident showing the precise locations of acid pools and the trajectories of the streams of spilled acid. Current practice is for a member of the emergency response team or accident investigation team to make a rough sketch of the spill, without any precise distances or reference points. When a question arises at a later date, it is difficult to recreate the original scenario with confidence.

6.4.8 Post-Spill Monitoring

After the immediate response action has been completed, pH measurements of soil, surface water and nearby drinking water wells should continue to be taken until such time as no residual problem is seen to exist. Sampling intervals should be frequent in the first few days and weeks after the spill, when the rate of change is rapid, decreasing to progressively less frequent intervals until monitoring is no longer justified. Vegetation recovery should also be monitored during this period and such events as the first post-spill germination of grasses, forbs, shrubs and trees should be noted.

Inexpensive, field-executed pH tests will in most cases provide the level of monitoring information required. A simple but faithfully executed monitoring program is recommended over a more elaborate program which is unlikely to be implemented or which may be abandoned prematurely.

6.4.9 Long-Term Restoration Plan

Our investigations have led us to the conclusion that short-term response activity should concentrate on valuable resources immediately at risk and that long-term restoration of the site should be undertaken on a non-emergency basis with the benefit of adequate assessment, sampling, testing and consultation with local soils, agricultural and forestry experts. Present practice tends to compress short and long-term action into the immediate post-spill period, with the result that long-term restoration considerations are often sacrificed.

One of the most basic decisions that must be made is whether any long-term restoration measures are warranted. The Springhill Spill is a case in point. Although no post-spill program to restore pH and soil fertility has been undertaken, natural recovery on the portions of the site disturbed by acid (but not physically disturbed) has been good. Since the land is not in production for either agricultural or forestry purposes, there is no compelling reason for an expensive restoration program. A similar argument would apply to many other areas of low agricultural and forestry potential, including extensive areas of the Canadian Shield.

In areas of cropland, improved pasture and even in some areas of unimproved pasture and high quality forest stands, a site restoration program may be justified and indeed may be demanded by the owner of the land. Such restoration measures may also be required because the spill occurred at a highly visible location where there are severe aesthetic implications. In all of these cases some variant on a conventional agricultural liming program is the appropriate response.

The program should start with the taking of soil samples for lab tests to determine the quantity of lime required. In the case of soils that are normally tilled, lime, preferably in the form of crushed dolomite, should be applied by conventional lime spreaders and worked into the furrow slice. The soil should also be fertilized following liming, particularly to replace potassium which may have been lost. Improved and unimproved pastures that can be tilled should be plowed under, treated in the same manner as cropland, and reseeded when pH has stabilized at an appropriate level.

In unimproved pastures with thin rocky soils the above techniques may not be practical, and surface application of crushed dolomite or limestone may be the only realistic restoration method. In broken terrain, where the use of conventional agricultural liming equipment is impractical, it may be necessary to resort to labour intensive liming techniques using equipment scaled to garden-sized applications. An alternative to this approach would be aerial application of lime by helicopter. A third approach that should be considered is to spray limewater or a similar dilute neutralizing agent to the site for spraying on the affected area. If the area still has living vegetation, the advice of a plant physiologist should be sought in determining whether the alkalinity of the neutralizing agent will have any adverse effect on the vegetation.

A great deal of flexibility is possible in long-term restoration of transportation-related spills since, by virture of the fact that the spill is located on a transportation route, virtually any type of material or equipment can be shipped to the site, given sufficient lead time. In planning the type of restoration, the various options should be fully explored from an environmental and economic standpoint before the restoration technique is selected.

After the initial fertility restoration treatment, a set of soil samples should be taken for laboratory testing to determine the success of the treatment. In some cases, a second or even a third round of treatment may prove necessary to restore pre-spill conditions.

The long-term restoration plan should consider the disposition of dead trees trunks and shrub stems resulting from the spill. The decision on whether this material should be removed should take into account aesthetic considerations, as well as such factors as fire hazard and the control of insects.

6.5 FUTURE RESEARCH

The field program provided a good understanding of the recovery from a sulphuric acid spill of a site with coarse-textured, free-draining, naturally acidic forest soils. The information collected is applicable to large areas of Canada where sulphuric acid spills might occur, including much of the vast Canadian Shield area.

The main drawback of studying an actual spill site is that many of the factors are beyond the control of the researcher. In the case of the Springhill Spill, past conditions on the site and chronology of events leading up to the present conditions had to be reconstructed from diverse sources. Moreover, the sampling program involved some compromise, in that its purpose was to both locate the boundaries of the area affected by the spill and to sample the variability within that area. Finally, the spill site was sloping and was extremely heterogeneous in soil characteristics, making the interpretation of trends in the data a difficult task.

If future research on the effects of sulphuric acid spills is undertaken, we believe that the most fruitful approach would be to run a series of test spills on level sites of internally homogeneous character with respect to soils and vegetation in several representative areas of Canada. The sites would include both coarse and fine-grained soils of both calcareous and non-calcareous nature in both agricultural and non-agricultural situations. A

full time sequence of soil chemistry and vegetation data would be developed from a time prior to the test spill to several years after the spill. A range of optional response measures and treatments could be tested at each location and the optimum approach for each situation determined. With this type of data a more comprehensive and regionally oriented set of recommended treatments could be developed.

REFERENCES

Adams, F., editor, Soil Acidity and Liming, No. 12 in the series "Agronomy", Madison: American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc., 1984.

Bennett, G.F., F.S. Feates and I. Wilder, Hazardous Materials Spills Handbook, New York: McGraw-Hill.

Braley, G.K., "Treatment of sulfur acid spills", Proceedings Hazardous Material Spills Conference, p 139-143, Milwaukee, Wisconsin, 1982.

Buckman, H.O. and N.C. Brady, The Nature and Properties of Soils, 7th Ed. 654 pp., New York: Macmillian, 1969.

Canada Environmental Protection Service, Sulphuric Acid and Oleum, Environmental and Technical Information for Problem Spills (ENVIROTIPS), Environment Canada, Ottawa, 1984.

Canada Environmental Protection Service, Manual for Spills of Hazardous Materials, Environment Canada, Ottawa, 1984.

Canadian National Railways, "Railway accident information report, Atlantic Region, Springhill Subidivision", December 13, 1978.

Fizer, J.C., "Transporting hazardous materials by rail", Proceedings of 1976 National Conference on Control of Hazardous Materials Spills.

Fox, R.L., R.A. Olson and H.F. Rhoades, "Evaluating the sulphur status of soils by plant and soil tests", Soil Science Society of America Proceedings, Volume 28: 243-246.

Glenn, W.M. and D. Orchard, Hazardous Waste Management Handbook, Third Edition, Toronto: Corpus, 1984.

Globe and Mail, "Sulphuric acid spills into Ontario creek", p.13, June 11, 1984.

Globe and Mail, "CN train derails near North Bay spilling sulphuric acid into river", p.13, June 11, 1984.

Grande Prairie Herald, "Acid spill controlled", p.3, January 31, 1985.

LaHaye, G.J., "Pollution complaint and spill report, sulphuric acid and diesel fuel", Ontario Ministry of the Environment, June 9, 1984.

Mercer, B.W., G.W. Dawson, L.L. Ames, J.A. McNeese and E.G. Baker, "Current methodology for disposal of spilled hazardous materials", Proceedings of the 1978 National Conference on Control of Hazardous Material Spills, p.190-195, Florida, 1978.

Moulins, L.J. and G.D. Plannell, "Neutralization et atténuation des impacts d'un déversement de 3600 tonnes d'acide sulfurique concentré", Proceedings of the Technical Seminar on Chemical Spills, p.235-260, Environment Canada, Toronto, 1983.

Ottawa Citizen, "CN rail freight train spills sulphuric acid after derailing", November 24, 1983.

Pilie, R.J., R.E. Baier, R.C. Ziegler, R.P. Leonard, J.G. Michalovic, S.L. Pek and D.H. Bock, Methods to Treat, Control and Monitor Spilled Hazardous Materials. U.S. Environmental Protection Agency, National Environmental Research Centre, Cinicinati, Ohio, EPA-670/2-75-042, June, 1975.

Prince Albert Herald, "Clean up begins on acid spill near La Loche", p.1 March 7, 1981.

Saint John Telegraph Journal, "Tank car leaks acid", p.2, November 25, 1983.

Sheldrick, B.H., editor, Analytical Methods Manual, Land Resource Research Institute, 1984.

Simmons, R.G. and L. Trip, "Sulphuric acid car derailment - Springhill, N.S." Environment Canada memorrandum, January 3, 1979.

Temple, R.E., W.T. Gooding, P.F. Woerner and G.F. Bennett, "A new universal sorbent for hazardous spills," Proceedings 1978 National Conference on Control of Hazardous Material Spills, p.382-383, Florida, 1978

Tisdale, S.L. and W.L. Nelson, Soil Fertility and Fertilizers, 694 pp., New York: Macmillan, 1975.

Thomas, G.W., "Exchangeable cations", in Miller, R and D. Keeney, editors, Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties, second edition, Madison, Wisconsin: American Society of Agronomy, 1982.

Thomas, G.W. and W.L. Hargrove, "The chemistry of soil acidity", p.3-56 in Adams, F., editor, Soil Acidity and Liming, No. 12 in the series Agronomy", Madison, Wisconsin: Americah Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc., 1984.

Toronto Star, "Team mops up mess from CN detrailment", June 12, 1984.

Transport Canada, Transport Dangerous Goods Dangerous Occurrence Report 1981-1983, Evaluation and Analysis, Transport Dangerous Goods, Ottawa, August, 1984.

U.S. Department of Transportation, 1984 Emergency Response Guidebook for Hazardous Materials Incidents, DOT P 5800.3, Materials Transportation Bureau, Washington, 1983.

U.S. National Transportation Safety Board, "Denver and Rio Grande Western Railroad Company train yard accident involving punctured tank car, nitric acid and vapor cloud, and evacuation, Denver, Colorado April 3, 1983", Railroad Accident Report NTSB/RAR-85/10.

U.S. National Transportation Safety Board, "Release of hazardous waste acid from cargo tank truck, Orange County, Florida, March 6, 1984", Hazardous Materials Investigation Report NTSB/HZM-85/01.

Vanderkooy, N. "Sulphuric acid spill - North Bay, March 28, 1975 - Sequence No. Ont. 028", Environment Canada memorandum, April 16, 1975.

APPENDIX A

MULTIVARIATE ANALYSIS

Data Transformations

Chemical concentrations and population estimators typically have a right skewed distribution (with the predominance of values being less than the mean). To be used in parametric statistical methods which assume a normal distribution with the values clustered symmetrically around the mean, such data must be subjected to a transforming function. For right skewed variables for which the values are all greater than or equal to zero, the logarthmic function is commonly used in the following form:

$$x' = \log(x+c)$$

where x is the untransformed value, x' is the transformed value and c is a positive constant which is used to prevent taking a logarithm of zero and which can be chosen to achieve the most normal distribution of x'. Note that the base of the logarithm is irrelevant since most tests ignore the scale of the variables. Otherwise it suffices to use the same base consistently.

Ratios and proportions can be right or left skewed and for these any of the following transformations may be used depending on the degree of skewness to be corrected:

Right skewed:	Left skewed:
$x' = (x+c)^{(1/p)}$	$x' = x^p$
$x' = \log(x+c)$	$x' = \exp(x)$
$x' = \sin(x*Pi/2)$	$x' = \arcsin(x)/(Pi/2)$

where Pi is the trigonometric pi constant, p is a power factor greater than one, and c is a constant as above. The power functions tend to be less extreme than the logarithmic/exponential functions which in turn are less

extreme than the sine and arcsine functions. Note, however, that the sine and arcsine functions are only valid for use with variables such as proportions which are strictly within the range of zero and one, inclusive, and also that the transformed values from these functions remain in that range with the zero and one points being preserved (Legendre & Legendre, 1983).

Species Diversity

Given a set of population estimates for all species occurring in a given environmental unit (plot), it is possible to calculate an index which measures both the number of species present and the evenness of their relative abundances. Such measures are generally referred to as species diversity indices. The Shannon-Wiener function is commonly used for this purpose:

$$H = -\sum_{i=1}^{n} (P_i)(\log_2 P_i)$$

where the sum is over all species i and P_i is the proportion of the population of species i in the total population of the environmental unit. Note that the base of the logarithm is not important, but traditionally base 2 is used (Legendre and Legendre, 1983; Pielou, 1969; Krebs, 1978).

For a unit containing a single species, the value of H is zero while for a unit containing N species with equal population levels, the function result is $\log_2(N)$ which is the maximum for the function in a unit of N species. The more the population of one or more species exceeds that of the others, the lower the value of H will be. A measure of species eveness or "equitability" can be computed as:

$$E = H/\log_2(N)$$

where N is the number of species present in the environmental unit. The value of E is in the range of zero to one, inclusive. Species diversity and evenness values were calculated for the shrub and ground vegetation data

for each 5m x 5m quadrat and were used as variables in the cluster analysis of the integrated data sets.

Cluster Analysis

Clustering was used to classify the 25 quadrats in the site (as cases) based on the populations of a specific set of species or other parameters (as variables). The technique used was hierarchical clustering using Euclidean distances and centroid linkages. This means that to start, the distances between all pairs of cases are calculated as the square root of the sum of squares of the differences between the values of each variable. The nearest two cases are taken as the first cluster. The average values of the variables over the two cases are considered as a new case, the cluster "centroid". The process then repeats comparing the distances between the centroids and the remaining unclustered cases and joining the nearest two until all cases have been joined.

For the purposes of drawing cluster diagrams, the mean amalgamation distance was used. This is the average between the distances at which the first and last clusters were joined. Lines were drawn around quadrats which were connected into a cluster at or below this distance while quadrats joined at greater distances were considered as unclustered.

Note that for this analysis, variables are usually standardized to a common scale by subtracting the mean and dividing by the standard deviation. Thus, distances are calculated on variables relative to their own range of variation. This might not be done in instances where all variables are of the same type and it is desired that values of greater magnitude be given more importance, such as with population level estimates (Hartigan, 1975).

Software

The cluster analyses were run using the BMPD2M program from the BMDP Statistical Software Package (Dixon, et al., 1983). Other multivariate tests

were also run using this package. Data summaries and t-tests were generated using the SPSS System, version 9 (Nie, Hull, et al., 1975 & 1981). Other data processing tasks, including the calculation of Shannon-Weiner diversity index values, were performed by programs developed by P. Lane & Associates Limited.

Soil Types and Chemical Parameters

Chemical concentrations tend to be right skewed and so the variables for calcium, magnesium, sodium, potassium, and sulphate concentrations, acidity, and conductivity were all log transformed. pH is often normally distributed but in this case was slightly right skewed, so it was transformed by the square root function. The soil types, although not proper metric parameters, were also treated similarly. Being right skewed, they were log transformed.

It was noted in the analyses, that the three soil types were strongly inter-correlated, with the drainage index being negatively correlated with indices for gravel content and slope. Given the assignations of these indices, this implies that high gravel content, rapid drainage, and uniform slope tended to occur together. In later analyses, in which variables from all data sets were combined, the number of variables which could be included in any one test was limited. Therefore, because of this correlation, only drainage was used with no loss of information.

Similarly, it was discovered that calcium, magnesium and potassium values were correlated so that only calcium was used in the final analyses. Acidity and conductivity did not display strong variance patterns and were also dropped in final analysis.

Ground Vegetation

There were 70 species of ground vegetation for which percent ground cover was measured in 10 one meter square plots randomly located within the 5 meter square quadrats. For each species, the average percent cover over the 10 plots for each quadrat was calculated. The total percent cover over all

species, the average percent cover over the 10 plots for each quadrat was calculated. Note that this value was not necessarily equal to 100 and was often greater because of patches where two or more species overlapped. Values listed in the data tables as "≤ 1" were treated as 0.5 percent.

The proportion of cover for each species over the total for all species in each quadrat was calculated. From these values, the Shannon Wiener diversity index was calculated for each quadrat.

The species list was then compressed from 70 species to 11. This was accomplished by first combining most species to genus. In one case (Solidago bicolor) this was not done because this species was considered to have significantly different habitat requirements than other species of Solidago which were present in the study area. Next, those species which occurred only once in the data set or which accounted for less than 0.5 percent cover summed over all quadrats were deleted. After these procedures, 35 species remained.

To make the final selection, the data were sorted so that the species having the greatest percent cover values came first in each quadrat. Those species required to get at least 60 percent of the total ground cover in each quadrat were selected. Taking the species that met this criterion in any one quadrat resulted in a list of 11 species which was used for most of the analyses. The total percent cover for these species was over 75% of the percent cover for all species in every quadrat.

For the final tests with the combined data, the correlations were checked as with the soil types and chemical parameters and a somewhat subjective selection of 7 species was made. Note, however, that the total percent cover and species diversity values were calculated using the full species list.

The percent coverage values for species were right skewed, as are most population level estimators, and they were log transformed. Species cover proportions were also right skewed, but less so, and were transformed using the square root function. The total percent cover over all species was, oddly enough,

left skewed and was normalized by taking it to the third power. The diversity values were also left skewed and were transformed by the exponential function.

Shrub Stem Basal Area

The total stem basal area over all individuals for each of 15 shrub species was measured in each quadrat. These values were expressed as square meters per hectare. Areas of both living and dead steam were measured separately for all species and quadrats.

These data were processed in much the same way as the ground vegetation. Using the data for live stems, total basal area and diversity over all species and proportions of basal area for each species over the species total were calculated for each quadrat. An additional parameter, the ratio of total dead stem area to live stem areas, all species in each quadrat was also calculated.

Species occurring only once were deleted. This left nine species which were used in all analyses except the final combined test where consideration of the inter-correlations led to a selection of six species.

There was one quadrat where there were no shrubs found. For this case, all variables were set to zero including the diversity index and the dead stem area over live stem area ratio which would technically be undefined.

Species and total areas were right skewed and were log transformed. The diversity values, the species proportions, and the dead over live stem area ratios were all transformed by the square root function.

Shrub Stem Densities

The number of stems over all individuals of shrub species in the quadrats were measured along with the stem basal area and expressed as number of stems per hectare. The data were processed and transformed exactly as for the basal

areas. In the analyses, however, these data did not provide any results not found from the shrub basal areas. The latter were judged to be the better estimator of population level and so stem densities were not used in the final analyses.

Tree Rings

From the tree ring data, the mean age of the ten dominant (tallest) trees in each quadrat were taken. This value is an indication of the extent to which trees survived the acid spill. The values were transformed using the log function.